NBS

Technical Note 40-10

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE NO. 10—DECEMBER 1959

J. W. WRIGHT, L. R. WESCOTT,
AND D. J. BROWN

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

The CRPL has initiated a program for large-scale computation of electron density profiles from ionospheric vertical soundings. Scaling is performed at field stations, permitting computation of hourly profiles at the Central Laboratory. These profiles are combined to form hourly mean quiet profiles for each station and month. The results of this program for the month of December are illustrated graphically. This report is the tenth of a series illustrating the electron density variations in the mean quiet ionosphere between latitudes 15°N and 50°N along the 75°W meridian.

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE No. 10 - December 1959

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Central Radio Propagation Laboratory

I. Introduction

Part of the basic responsibility of the Central Radio Propagation Laboratory is to gather ionospheric, solar, or other geophysical data necessary in the pursuit of research leading to improvements in radio communication and knowledge of the earth's upper atmosphere. The existing network of ionospheric vertical sounding stations is an important source of such data. Typically, the radio sounding data directly provide observations of peak electron densities (corresponding to "critical" frequencies foE, foF1, foF2), data on Sporadic E, and certain derived propagation data such as maximum usable frequencies or MUF factors (Smith, 1939).

In fact, the vertical sounding is potentially capable of providing the complete electron density profile of the underside of the ionosphere (i.e., below hmax F2) and of providing a basis for extrapolation to much greater altitudes. However, because a lengthy and difficult calculation is required, little of this work had been done until quite recently when techniques and computers have become available and the exigencies of the IGY and satellite programs have made it imperative.

In the course of its development of facilities for electron density profile calculations, the CRPL has succeeded in devising means by which basic data for this purpose may be scaled by the individual field stations, thereby decentralizing and simplifying the most onerous part of the work. Through its own station network and those of the U. S.

Army Signal Radio Propagation Agency, and through cooperation with closely associated stations in other countries, the CRPL has initiated an extensive systematic data reduction program, from which hourly electron density profiles are being computed for the following stations:

Puerto Rico (NBS, January 1959)
Grand Bahama Island (U. S. Army Signal Corps, February 1959)
Fort Monmouth, New Jersey (U.S. Army Signal Corps, Feb. 1959)
White Sands, New Mexico (U.S. Army Signal Corps, March 1959)
St. Johns, Newfoundland (Def. Res. Tel. Establ. Canada, June 1959)
Adak, Alaska (U.S. Army Signal Corps, June 1959)
Okinawa, Ryukus (U.S. Army Signal Corps, June 1959)
Thule, Greenland (U.S. Army Signal Corps, July 1959)
Huancayo, Peru (January 1960)
Talara, Peru (January 1960)
Baguio, Philippines (February 1960)

Affiliation and approximate date of initial participation in this program are given in parentheses.

The hourly electron density profiles are extensively used in the research programs of CRPL and are supplied directly to certain other agencies as part of various research and practical activities. However, in this comparatively early stage, broad dissemination of the computed data is a somewhat difficult problem.

In an attempt to make at least a summary of the results of the program widely and rapidly available, the CRPL has initiated the present series of reports. These provide graphical representations of the monthly mean quiet hourly electron densities from certain of the stations in the preceding list, from which a fairly clear picture of the local ionosphere morphology may be obtained.

These reports contain N(h) data for the stations at Newfoundland, Fort Monmouth, Grand Bahama Island, White Sands, and Puerto Rico. Pertinent facts concerning these stations are given in the following table:

Table 1

		Geomag. Coordinates		Geog. Coordinates	
	fH	Lat.	Dip		
St. Johns, Newf.	1.38 Mc/s	58.5°N	72°N	47°33'N	52°40'W
Ft. Monmouth, N.J.	1.46	51.7°N	71.5°N	40°15'N	74°01'W
White Sands, N.M.	1.30	41.2°N	60°N	32°24'N	106°52'W
Grand Bahama Island	1.30	37.9°N	59.5°N	26°40'N	78°22'W
Puerto Rico	1.15	30°N	51.5°N	18°30'N	67°12'W

II. Description of Basic Data

True heights of reflection of radio waves are calculated from the observed or "virtual" heights by the method of Budden (1954); this method need not be described here, but it should be pointed out that full correction for geomagnetic field effects is made and that the usual restrictions to monotonic profiles apply.

Tabulations of the mean electron density data at 10 km intervals and certain related quantities are the bases for the graphs and charts. A sample for the Puerto Rico December data is given on Page 11. The table on the following page identifies the quantities appearing on the tabulation.

Quantity	Units	Remarks
Average Electron Density (N)	$x10^3$ = electron/cm^3 (10^{-5} on maps)	Body of table; given at each 10 km of height from the lowest hmin to 950 km.
NMAX	$x10^3$ = electron/cm^3 (10^{-5} on maps)	The mean value of Nmax.
COUNT		Count of the number of profiles entering the mean.
HMIN	Kilometers	The average height of zero or very low electron density, obtained by linear extrapolation of the electron density of the individual profiles.
HMAX	Kilometers	The average height of maximum electron density, determined by fitting a parabola to the upper portion of the individual profiles.
SCAT	Kilometers	One half of the half-thickness of the parabola best fitting the upper portion of the F-region profile. Approximates the scale height near the true HMAX.
SHMAX	$x10^{10}$ = electrons/cm^2 column (10^{-12} on maps)	Obtained by averaging the integration of the individual profiles between the limits HMIN and HMAX.
SHINF	$x10^{-10}$ = electrons/cm^2 column (10^{-13} on maps)	The average total number of electrons in a column to infinity obtained by extrapolation of observed profiles into the region above HMAX. (See text.)

The following particular features of the tabulated data should be noted:

A. Averaging process. Each hour of each day is identified with its magnetic character figure, Kp. For each hour, those days for which Kp is less than 4+ are included in the "quiet" average. The other days are similarly combined to form a "disturbed" average; however, this rarely has physical significance because the number of disturbed periods is usually small and the behavior of the ionosphere during disturbed hours is not consistent. Thus, graphs for these latter averages are not presented here.

B. Determination of hmax. The nature of the "true height" process is such that no direct measure of hmax F2 is obtained, the virtual height at Nmax being immeasurable. A useful procedure is to fit the portion near hmax F2 with a suitable curve and to determine hmax from this curve. A parabola is quite satisfactory for this purpose; it is fitted to two of the highest true heights and the measured value of Nmax (foF2).

C. Extrapolation of profiles above hmax. Before averaging, the individual profiles are extrapolated above hmax by a Chapman distribution of 100 km scale height. This assumed model seems to agree well with the few published measurements dealing with the profile of the F region above hmax (Wright, 1960). Extrapolation is necessary in order to calculate homogeneous averages near hmax, and the average profiles are, in fact, given to 950 km.

D. Integrated electron densities. The total number of electrons in a unit column of the ionosphere between the effective bottom (hmin) and hmax is called Shmax; it is obtained by numerical integration of the observed profiles between these limits. An estimate of the total electron content to infinity, based upon the Chapman model, is called Shinf. It is obtained by adding to Shmax the quantity $N_A = 2.82\,HNmax$ where H is an (assumed constant) scale height for the region above hmax. Current evidence (Wright, 1960) indicates H = 100 km, is an acceptable choice.

III. Description of Graphical Representation

The relative smoothness of mean quiet ionosphere data lends itself to various kinds of graphical presentation which offer convenient aids to the visualization of the height, geographic, and temporal variability of the ionosphere. Included here are three such graphical forms prepared from the tabulations described in Section II.

A. Vertical cross sections of the ionosphere along the 75°W meridian. Pages 12 through 35 give, for each hour, a vertical cross section of the mean quiet ionosphere along a meridian section, nominally the 75°W geographic meridian, for the month of December 1959. Contours are parametric in "plasma" frequency (f_N) related to electron density N by

$$12{,}400\ f_N^2\ (\mathrm{Mc/s}) = N(\mathrm{electrons/cm^3}).$$

The height of maximum electron density is represented by a dashed line. Note that the vertical scale is expanded about 5.5 times.

With the exception of White Sands, each of these stations is reasonably close to the 75°W meridian (see Table 1). There is the possibility that some of the anomalies imposed by White Sands on these contours are the result of the well-known longitudinal asymmetry of the ionosphere.

B. Local time vs. Latitude Maps. Another form of presentation, useful for indicating the two-dimensional geographic variations of the ionosphere, is that illustrated by the maps of pages 36 through 45. Here, for fixed levels in the ionosphere (150, 200, 250, 300, 350, 400 km), contours of electron density are drawn in the latitude vs. local time plane. To the extent to which longitude anomalies are negligible, these maps give also the longitude vs. latitude distribution of electron densities at the indicated heights when it is noon over the 75°W meridian. Similar maps for the peak density, Nmax; its height, hmax; its characteristic thickness, Scat; the total electron content to Nmax, Shmax; and the estimated total electron content, Shinf, are also shown.

C. Electron density vs. time curves (N(t) curves). The mean quiet diurnal variation of electron density between 150 and 400 km heights above the sounding stations is illustrated by these curves. Dashed lines are used wherever the electron density at any height falls below the peak density (i.e. when the height hmax F2 falls below the height for the curve in question.) Such electron densities are the result of the extrapolations by the Chapman model discussed in Section II C.

IV. Discussion and Applications of the Data

Mean quiet electron density data over wide geographic areas are essential for application to numerous problems of both practical and scientific interest. For example, the assessment of the radio refraction errors and Faraday rotation effects in satellite tracking requires a knowledge of the electron density profile in the direction of the satellite or an estimate of the electron density at the satellite itself. Alternatively these properties of the ionosphere, or estimates of the total electron content in a column, may be measured by observations from rockets and satellites, or from radar moon-echoes, and compared with ground-based observations of the kind shown here.

Frequently it will be necessary to use instantaneous density data because of the considerable variability of the ionosphere about the quiet mean. In such cases, the mean data are of value as a "reference level" in the design of the experiment; for example, in the choice of radio frequencies, satellite heights, antennas, etc.

Since electron density data represent virtually our only source of continuous, widespread data on the earth's upper atmosphere, such data also are essential to geophysical problems involving the electrical, neutral, and magnetic properties of the atmosphere.

For example, data on the vertical cross sections may be compared with theoretical expectations for the meridional height dependence of the quiet ionosphere. Several workers (Hirono, 1955; Martyn 1956) have investigated the equilibrium height (of hmax) for an ionosphere controlled by diffusion, height-varying electron loss rate, and uniform (or zero) vertical electron drift. The results are qualitatively in agreement with these observations in predicting a rise of hmax towards the equator in daytime and a reversal of this tendency at night.

The N(t) curves are perhaps the most physically significant representation of electron density data. The strong solar control at all levels and the important perturbations of this solar control in the upper F region may be easily seen.

Acknowledgments

We are indebted to Mr. A. H. Shapley for guidance in the initiation of this work, and to Dr. H. H. Howe for the development of the computer programs upon which the whole system heavily depends. This series of reports results from the combined efforts of the NBS Electron Density Profile Group, including at various times L. R. Wescott, L. Hayden, D. J. Brown, F. J. Burmont, I. Ford, N. Moore, M. Durham, G. Lira, under the direct supervision of G. H. Stonehocker. The cooperation of the U. S. Army Signal Radio Propagation Agency is gratefully acknowledged.

References

Budden, K. G., "A method for determining the variation of electron density with height (N(z) curves) from curves of equivalent height against frequency (h'(f) curves). Proc. Cambridge Conf. on the Physics of the Ionosphere, pp 332-339, September 1954, Pub. by the Physical Society (1955).

Martyn, D. F., "Processes controlling ionization distribution in the ionosphere," Aust. J. Phys. 9, pp 161-165, March 1956.

Hirono, M., "Effect of gravity and pressure gradient on vertical drift in the F2 region," Rpt. on Iono. Res. in Japan, 9, No. 2, pp 95-104, (1955).

Smith, N., "The relation of Radio Skywave Transmission to Ionosphere Measurements," Proc. IRE, 27, No. 5, pp 332-347, (1939).

Wright, J. W. "A model of the F region above hmax F2," Journal of Geophysical Research, 65, pp 185-191, January 1960.

AVERAGE ELECTRON DENSITY — KP BELOW 4.5

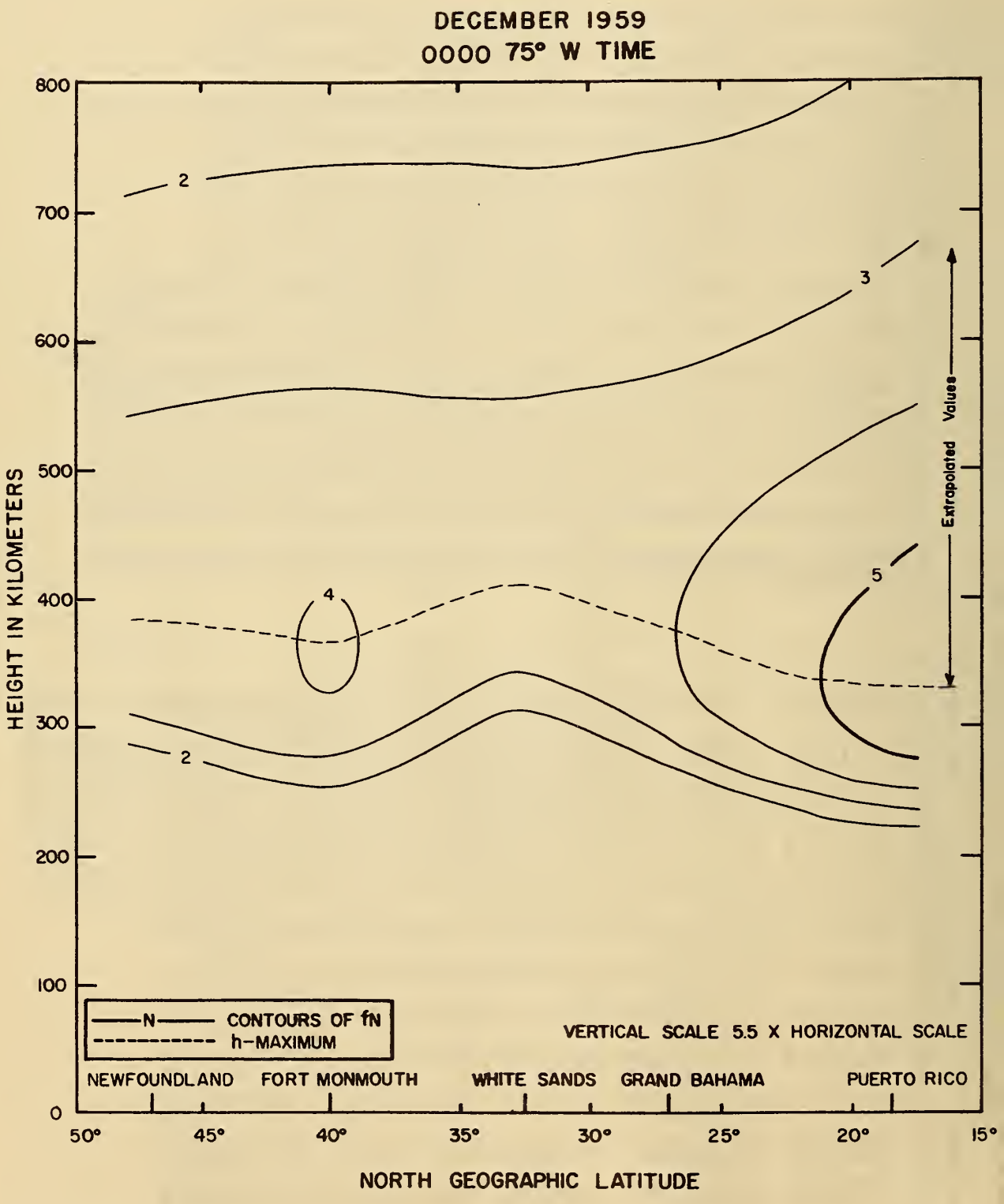
PUERTO RICO — 60 W — DEC 1959

TIME	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
COUNT	28	28	29	28	29	24	23	24	26	24	26	24
HMIN	219	222	213	219	257	246	230	221	110	109	110	109
RATIO	5.8	6.5	5.8	5.2	4.4	4.4	4.9	6.5	5.5	5.1	5.0	4.7
SCAT	46.6	40.3	49.2	61.1	62.1	60.1	55.3	41.3	39.3	43.3	44.4	49.9
NMAX	384	349	266	200	192	206	235	548	1291	1787	1991	1880
HMAX	320	311	309	340	385	377	347	306	276	281	282	287
SHMAX	231	185	162	161	163	173	173	290	822	1217	1412	1477
SHINF	1315	1169	912	726	704	753	836	1836	4465	6258	7029	6780
KM												
950	26.6	23.4	18.0	17.0	19.4	19.6	18.9	36.1	73.9	104	117	113
900	34.1	30.0	23.0	21.8	24.9	25.1	24.2	46.3	94.9	134	150	145
850	43.7	38.4	29.5	27.9	31.9	32.1	31.0	59.4	122	171	192	186
800	56.0	49.3	37.8	35.7	40.8	41.2	39.7	76.1	156	220	246	238
750	71.8	63.1	48.4	45.4	52.1	52.6	50.8	97.5	200	282	315	305
700	91.7	80.6	61.9	57.6	66.1	66.9	64.9	125	256	361	404	390
650	117	103	78.9	72.5	83.5	84.7	82.5	159	327	461	516	499
600	148	130	100	90.3	104	106	104	202	417	587	657	635
550	187	164	126	111	128	131	130	255	528	743	832	803
500	232	204	156	134	152	159	160	318	663	934	1044	1007
490	242	213	163	139	157	164	166	332	693	976	1091	1052
480	252	221	169	144	161	169	172	346	724	1019	1140	1098
470	262	230	176	148	165	174	179	360	756	1063	1189	1146
460	272	239	183	153	169	179	185	375	789	1109	1240	1194
450	282	248	189	158	173	184	191	389	822	1155	1292	1243
440	292	257	196	162	176	188	197	404	856	1203	1345	1293
430	302	266	204	166	178	192	202	419	891	1251	1399	1344
420	312	275	212	170	179	195	208	434	925	1299	1453	1395
410	322	284	216	174	180	198	213	448	960	1348	1507	1446
400	331	292	222	177	179	199	217	462	995	1396	1561	1496
390	340	300	228	179	177	200	221	476	1030	1444	1614	1546
380	348	308	233	181	174	199	225	489	1064	1492	1667	1595
370	356	314	238	182	169	197	227	501	1098	1537	1718	1642
360	362	319	242	183	163	192	228	512	1130	1581	1767	1686
350	368	324	245	182	155	184	227	522	1160	1623	1813	1728
340	371	326	248	180	144	175	225	530	1189	1661	1855	1765
330	373	327	248	177	134	163	220	536	1215	1695	1893	1798
320	371	326	248	173	122	149	212	538	1237	1725	1926	1826
310	365	322	245	168	109	132	200	536	1256	1750	1953	1848
300	354	314	240	160	93.8	115	185	527	1271	1768	1972	1861
290	338	301	231	151	82.3	97.7	167	508	1279	1777	1982	1864
280	313	282	221	140	70.1	81.9	147	477	1279	1771	1977	1850
270	280	256	208	127	56.8	63.8	123	427	1259	1733	1942	1808
260	238	221	190	111	44.4	46.6	97.6	356	1209	1655	1858	1729
250	187	182	168	93.2	33.0	31.5	75.2	269	1123	1525	1720	1612
240	135	140	141	73.8	24.5	22.5	50.7	177	992	1350	1526	1452
230	88.4	92.6	107	53.4	15.5	16.1	32.2	92.5	822	1127	1281	1252
220	48.3	51.3	71.7	34.9	9.0	10.1	20.1	36.1	642	887	1016	1025
210	16.3	24.5	37.5	21.0	4.5	4.1	8.4	15.0	473	670	778	806
200	6.0	7.8	16.8	6.8	1.9	.5	5.3	8.4	341	493	587	627
190			4.7	1.3	.3		2.1	5.3	246	368	447	489
180							.1	3.9	184	283	351	394
170								3.3	143	224	283	325
160								2.8	117	182	233	272
150								2.5	101	152	194	231
140								2.2	92.4	134	166	197
130								2.0	85.7	124	152	175
120								1.3	76.9	117	141	158
110								.2	15.6	54.6	62.7	80.4

AVERAGE ELECTRON DENSITY — KP BELOW 4.5

PUERTO RICO — 60 W — DEC 1959

TIME	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
COUNT	24	20	21	19	22	15	23	26	26	25	25	28
HMIN	110	110	111	111	111	112	211	200	204	230	226	217
RATIO	4.2	3.9	3.9	4.0	4.0	4.5	5.5	5.4	5.1	5.5	5.5	5.8
SCAT	54.1	57.9	59.4	59.0	59.4	54.3	49.0	47.7	51.4	46.7	47.1	44.7
NMAX	1631	1609	1627	1628	1612	1613	1470	989	663	571	516	461
HMAX	297	310	317	316	317	312	312	309	324	336	335	318
SHMAX	1455	1549	1592	1560	1510	1351	946	645	464	363	324	273
SHINF	6057	6088	6180	6153	6057	5901	5093	3435	2335	1975	1779	1572
KM												
950	103	108	114	113	113	111	101	66.8	47.9	44.5	39.1	32.2
900	132	139	146	145	145	143	129	85.6	61.4	57.0	50.1	41.2
850	170	178	187	186	186	183	165	110	78.7	73.1	64.2	52.9
800	218	228	240	239	238	235	212	141	101	93.6	82.3	67.8
750	279	293	307	306	305	300	272	180	129	120	105	86.8
700	357	374	392	391	390	384	348	231	165	153	135	111
650	456	477	500	498	496	490	443	294	210	195	171	141
600	580	606	635	632	630	621	563	373	267	246	217	179
550	732	764	799	796	793	783	709	471	335	308	272	226
500	916	953	993	991	986	973	883	587	416	379	335	280
450	1126	1165	1209	1207	1201	1186	1077	717	504	455	404	341
440	1170	1209	1253	1252	1244	1229	1117	744	521	470	417	353
430	1214	1252	1297	1296	1288	1272	1157	771	539	484	430	365
420	1259	1296	1340	1339	1330	1315	1196	797	556	497	443	377
410	1303	1338	1382	1382	1372	1356	1234	823	572	510	455	389
400	1346	1380	1423	1423	1412	1396	1272	849	588	522	466	400
390	1388	1419	1461	1462	1450	1434	1307	873	603	533	477	410
380	1429	1457	1497	1498	1486	1470	1341	896	616	541	485	420
370	1467	1492	1529	1531	1518	1503	1371	917	628	547	492	429
360	1503	1524	1557	1561	1546	1532	1399	936	638	550	497	436
350	1536	1551	1581	1585	1570	1556	1422	953	645	549	499	442
340	1565	1574	1599	1605	1588	1575	1441	967	649	543	498	446
330	1589	1591	1610	1618	1599	1588	1454	977	649	533	492	447
320	1607	1601	1612	1624	1602	1592	1460	982	643	515	478	443
310	1619	1601	1602	1616	1593	1584	1454	980	630	486	455	436
300	1621	1586	1576	1587	1566	1561	1431	965	607	448	422	422
290	1607	1549	1527	1536	1516	1516	1381	931	574	399	379	399
280	1571	1488	1455	1461	1443	1446	1301	877	529	339	327	367
270	1511	1399	1358	1364	1346	1347	1189	798	472	275	267	323
260	1421	1294	1243	1246	1231	1217	1038	700	403	208	210	265
250	1309	1167	1110	1115	1103	1068	838	579	323	145	154	201
240	1175	1025	969	969	957	899	599	444	242	92.2	106	137
230	1021	884	829	823	803	729	342	310	168	50.7	65.9	86.2
220	867	754	699	685	652	563	122	187	106	28.7	34.5	45.5
210	719	641	586	566	517	422	32.6	96.5	56.3	15.3	15.8	21.7
200	593	546	492	469	411	313	3.2	33.9	21.0	5.3	3.7	6.9
190	489	466	416	391	329	230		7.6	2.7	.5	1.4	.4
180	406	396	353	327	264	174		.5				
170	338	337	300	275	215	136						
160	283	289	255	232	178	112						
150	238	247	217	197	151	96.2						
140	202	209	189	172	133	86.4						
130	178	182	170	156	122	80.0						
120	164	166	154	137	110	68.1						
110	62.6	57.7	40.8	26.2	20.4	10.3						


DECEMBER 1959
0000 75° W TIME
HEIGHT IN KILOMETERS
800
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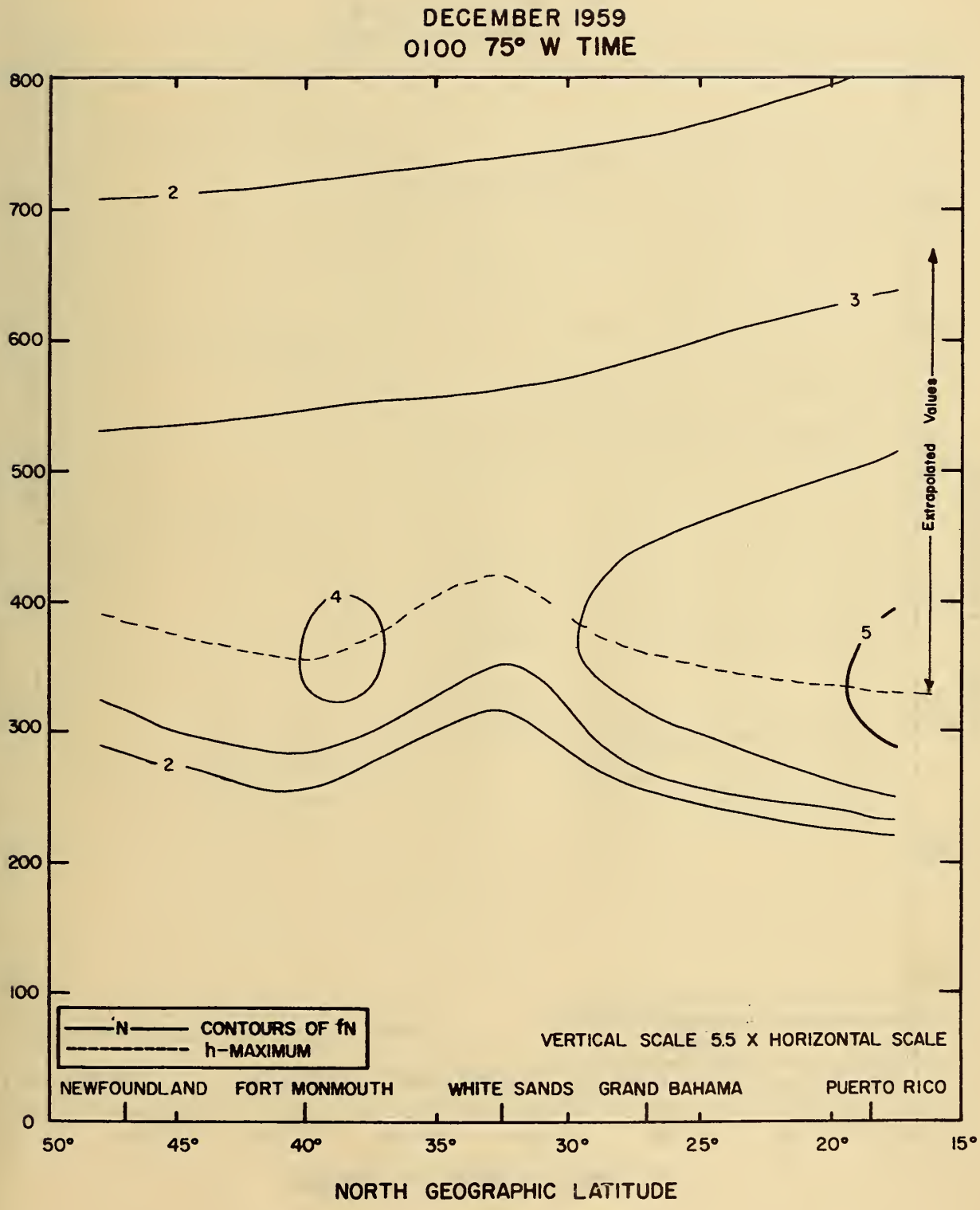
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
0100 75° W TIME
800
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400
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200
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4
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
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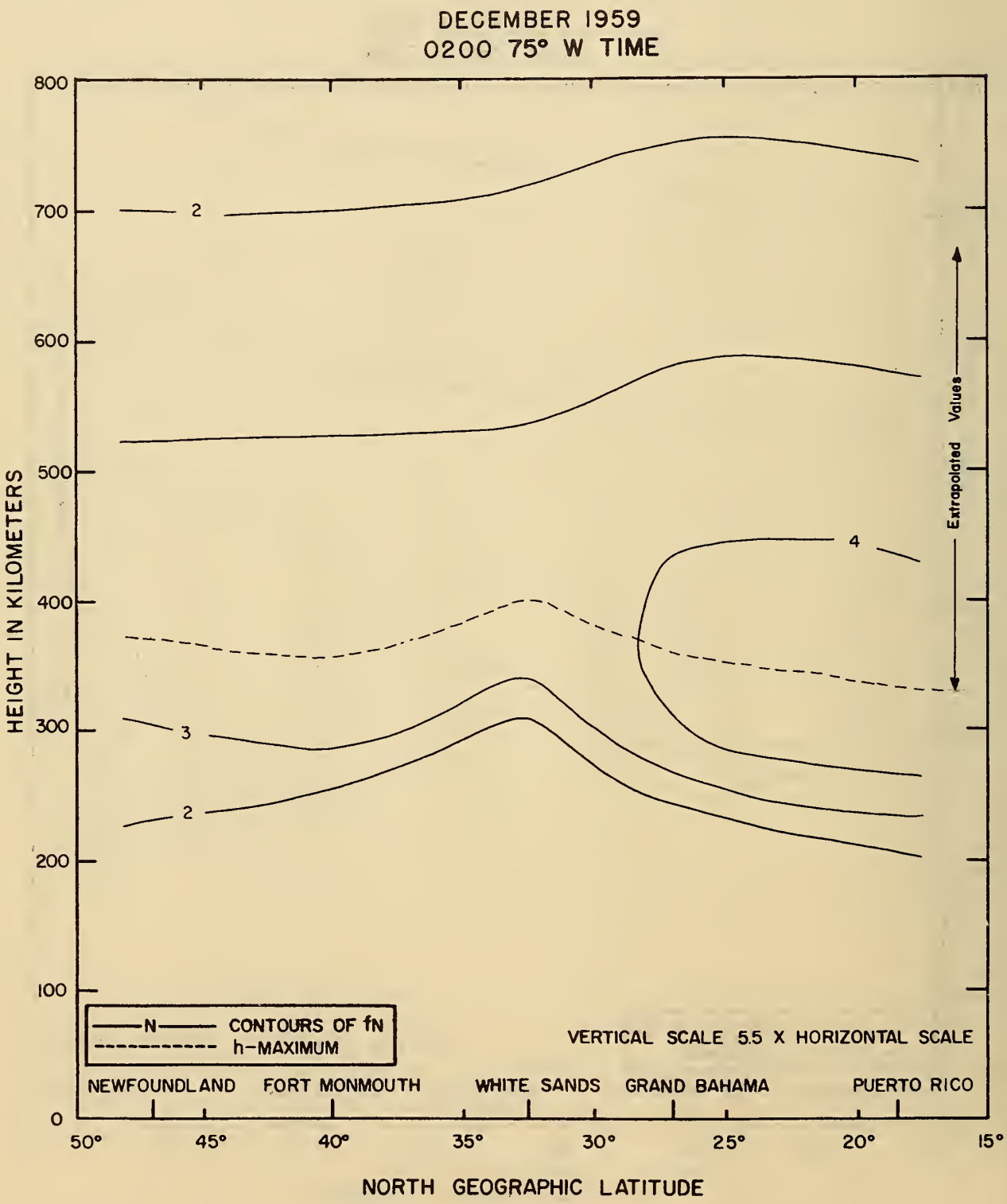
20°
15°
NORTH GEOGRAPHIC LATITUDE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0
HEIGHT IN KILOMETERS
2
2
3
4
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
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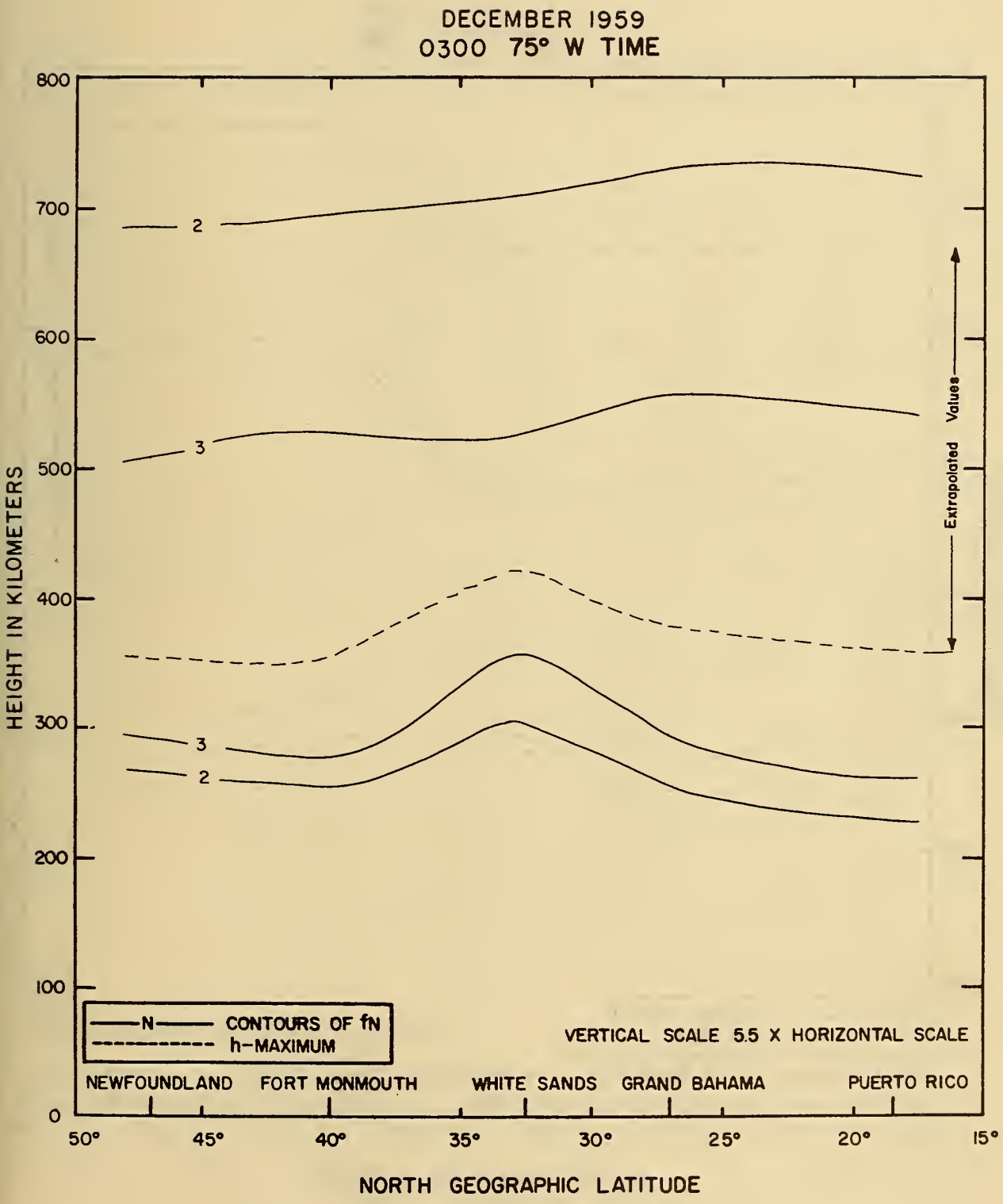
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
0300 75° W TIME
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HEIGHT IN KILOMETERS
2
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3
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
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25°
20°
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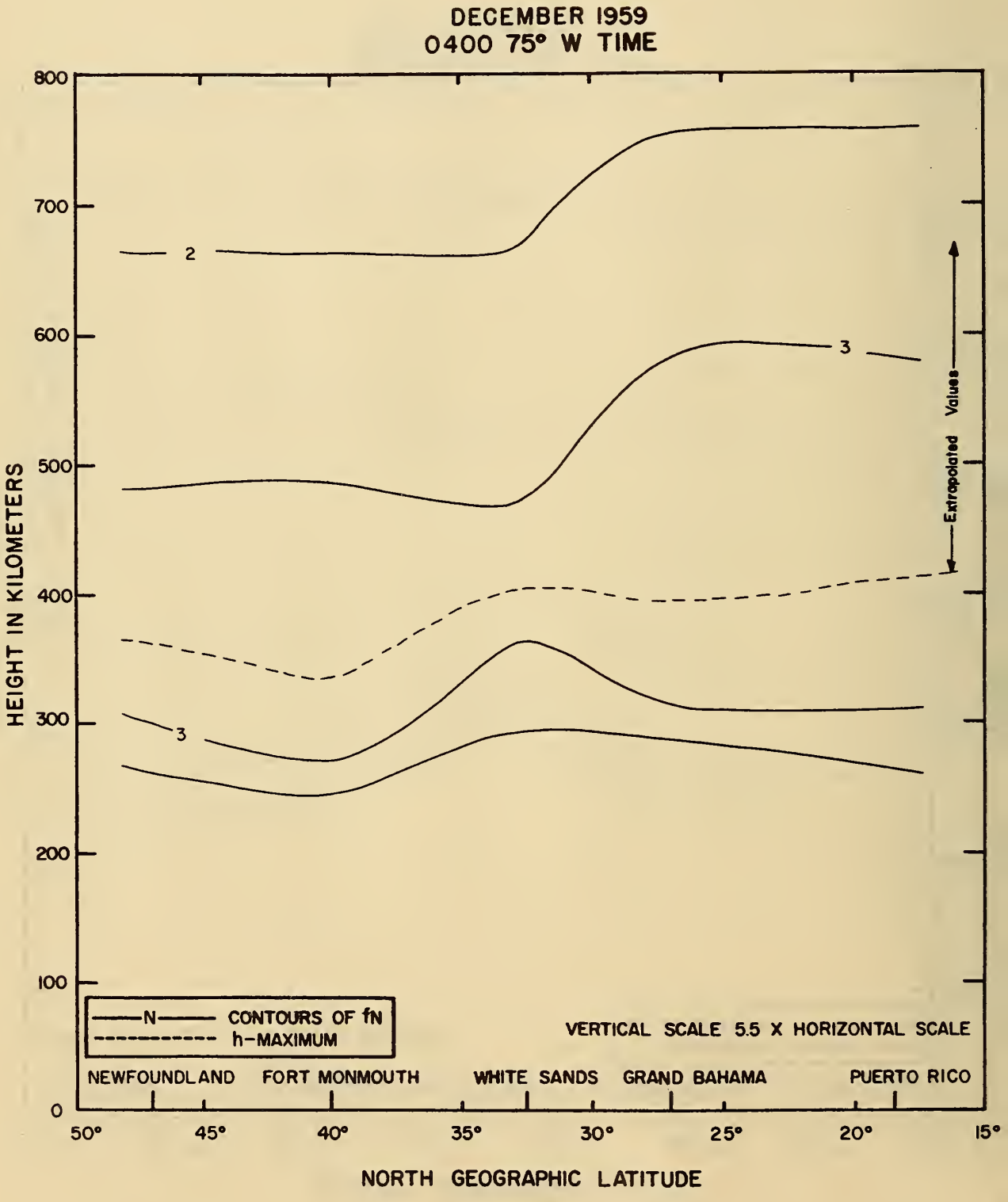
NORTH GEOGRAPHIC LATITUDE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0400 75° W TIME
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500
400
300
200
100
0
HEIGHT IN KILOMETERS
2
3
3
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
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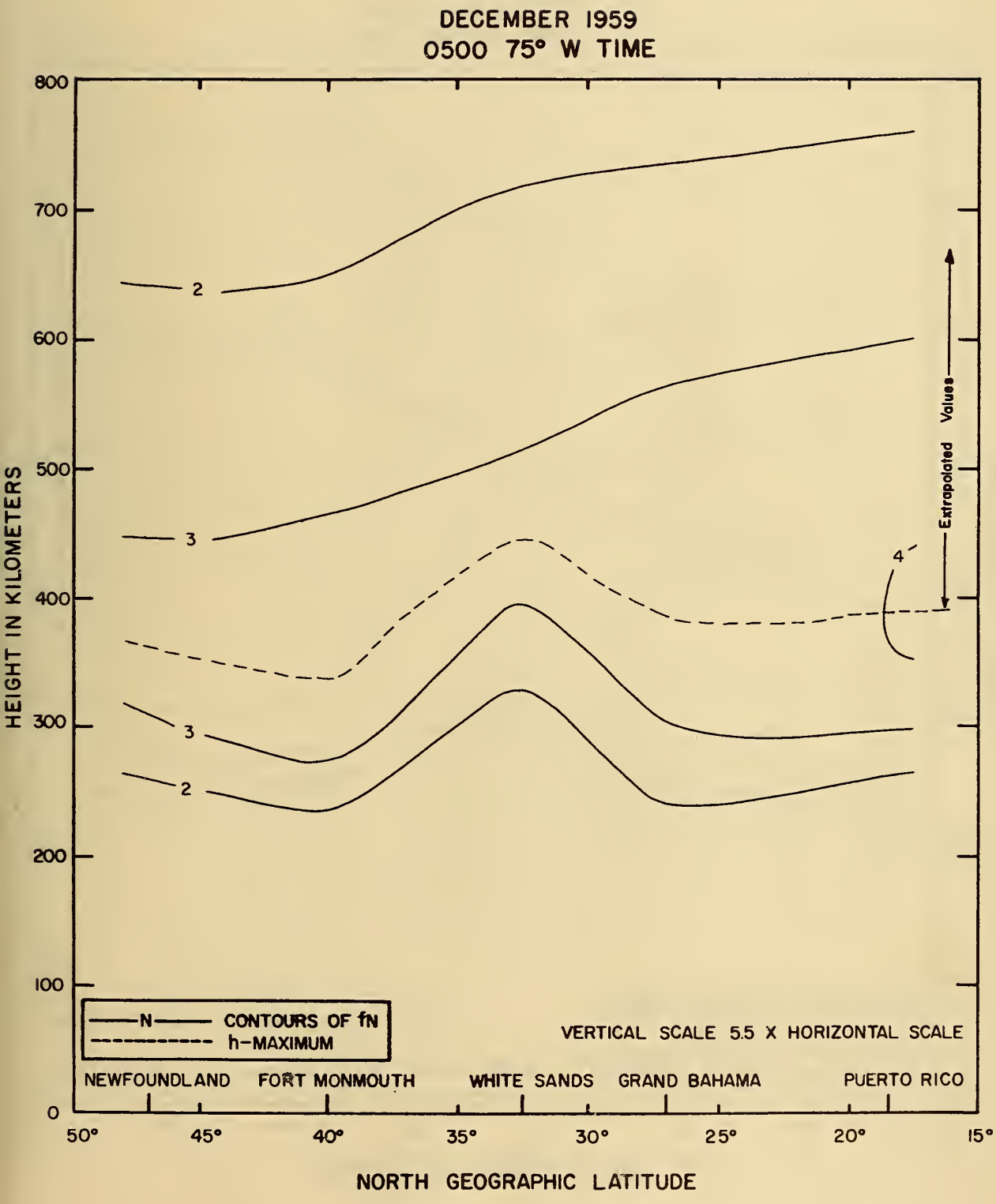
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE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HEIGHT IN KILOMETERS
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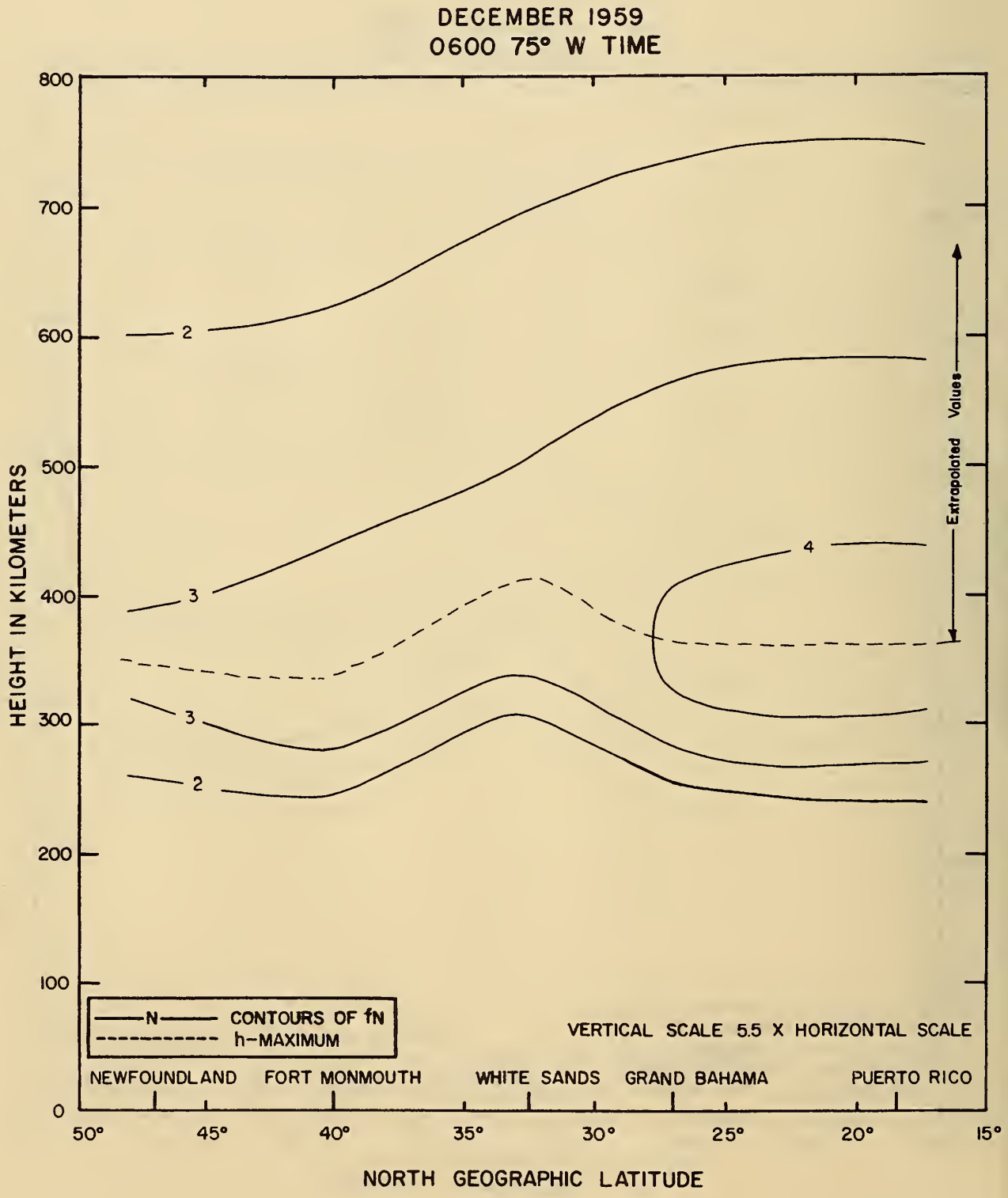
700
600
500
400
300
200
100
0
2
3
3
2
4
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
0600 75° W TIME
HEIGHT IN KILOMETERS
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700
600
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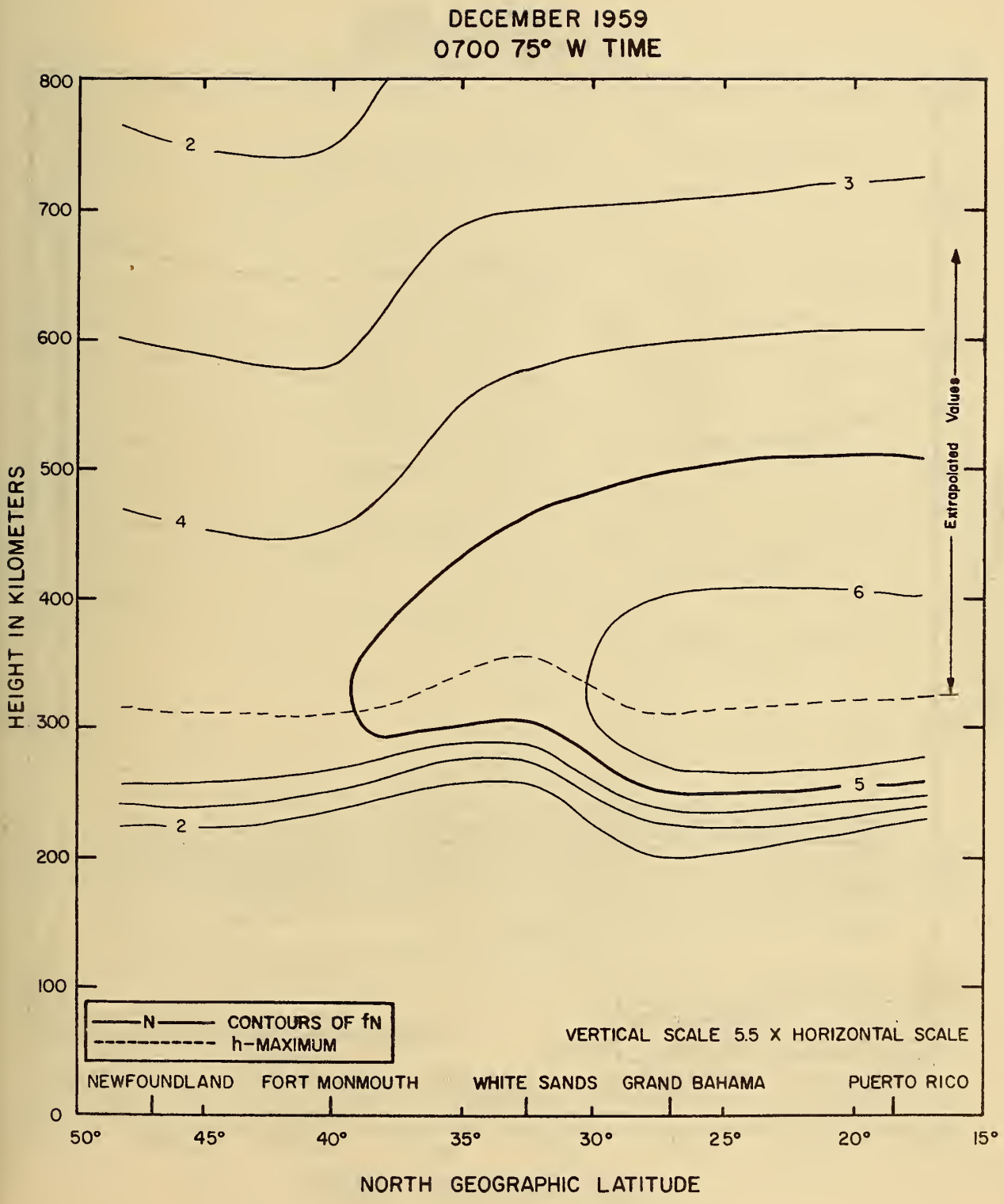
400
300
200
100
0
2
3
4
3
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
0700 75° W TIME
HEIGHT IN KILOMETERS
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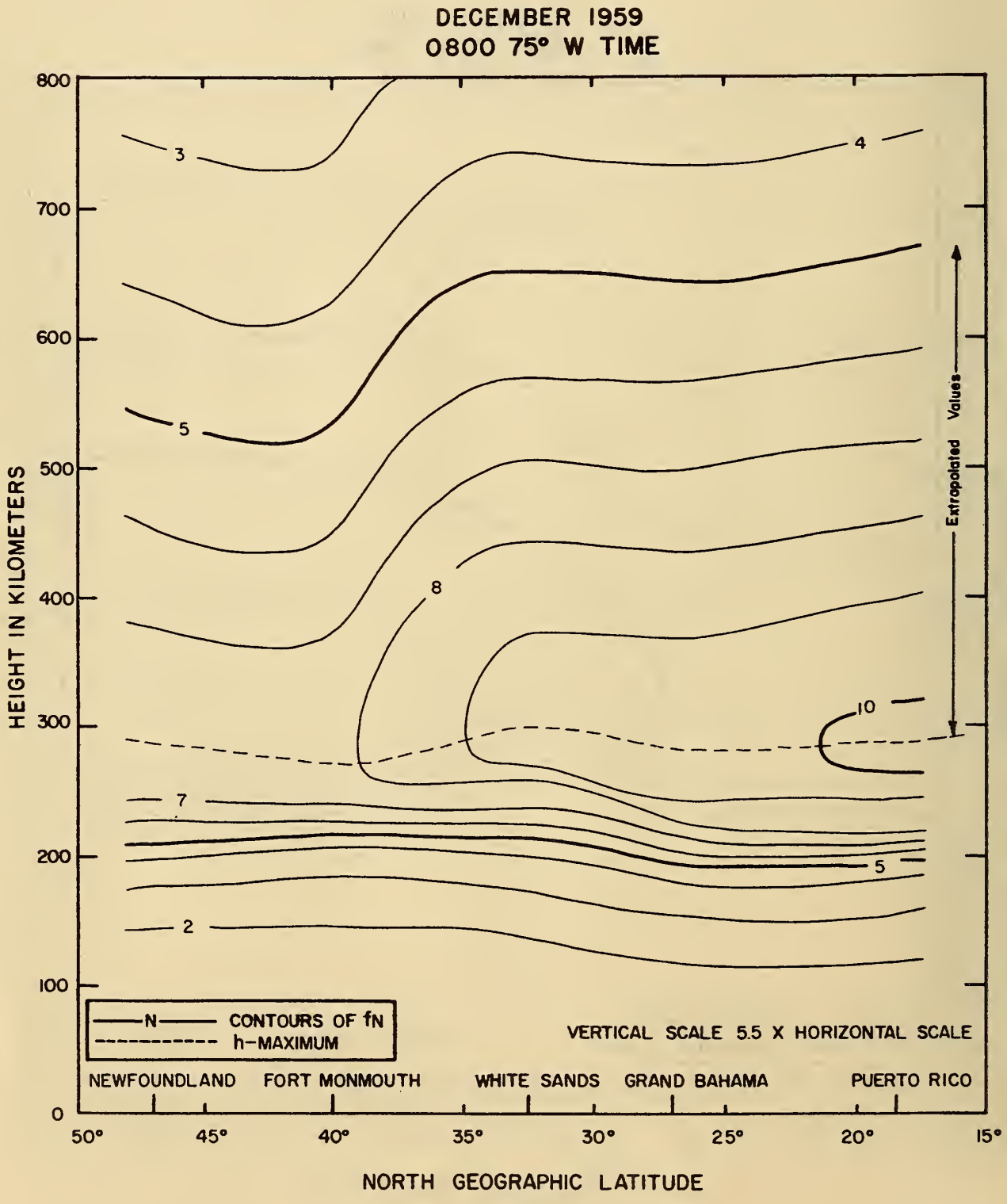
700
600
500
400
300
200
100
0
2
3
4
6
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
0800 75° W TIME
HEIGHT IN KILOMETERS
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700
600
500
400
300
200
100
0
3
4
5
8
10
7
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
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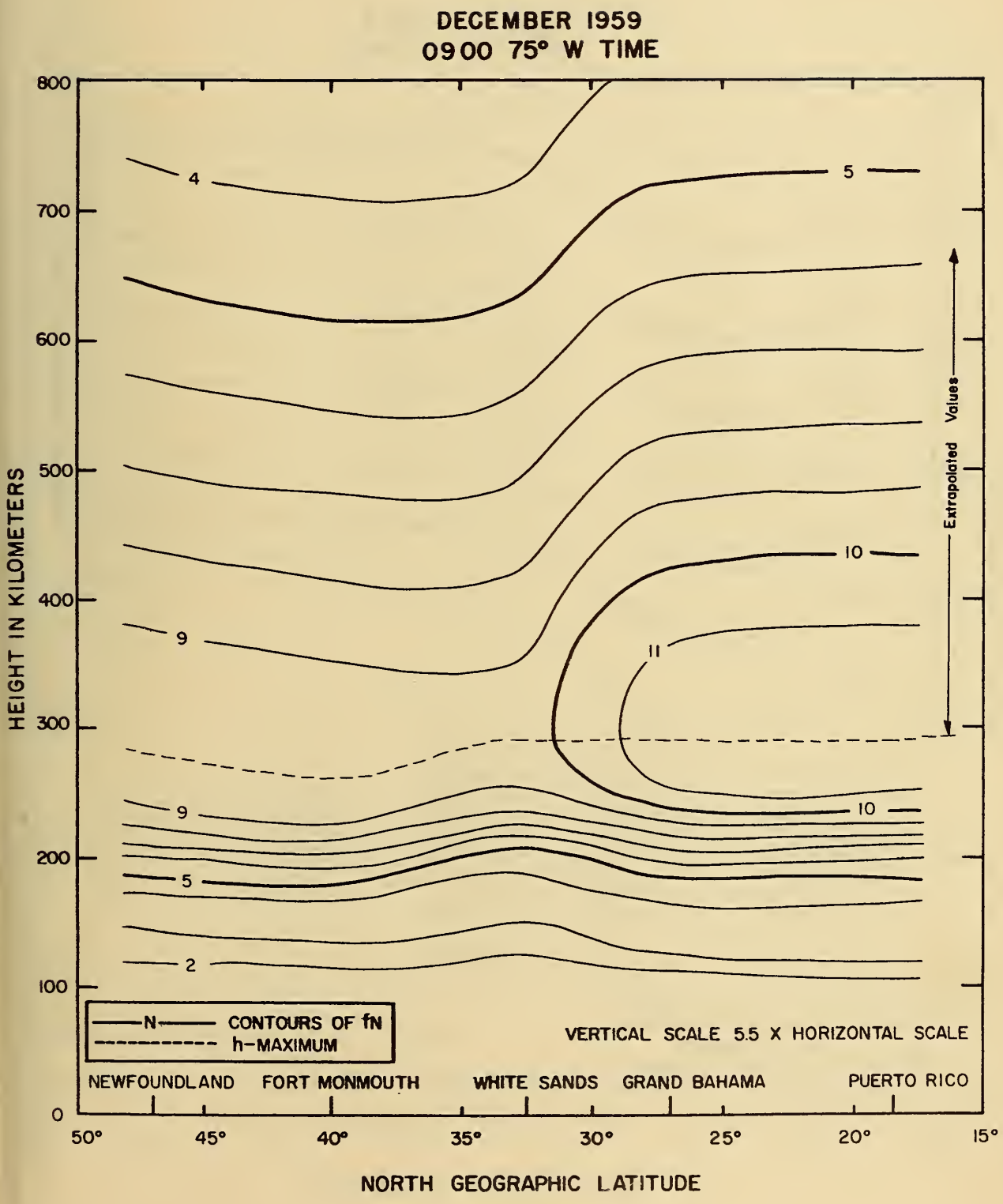
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
0900 75° W TIME
HEIGHT IN KILOMETERS
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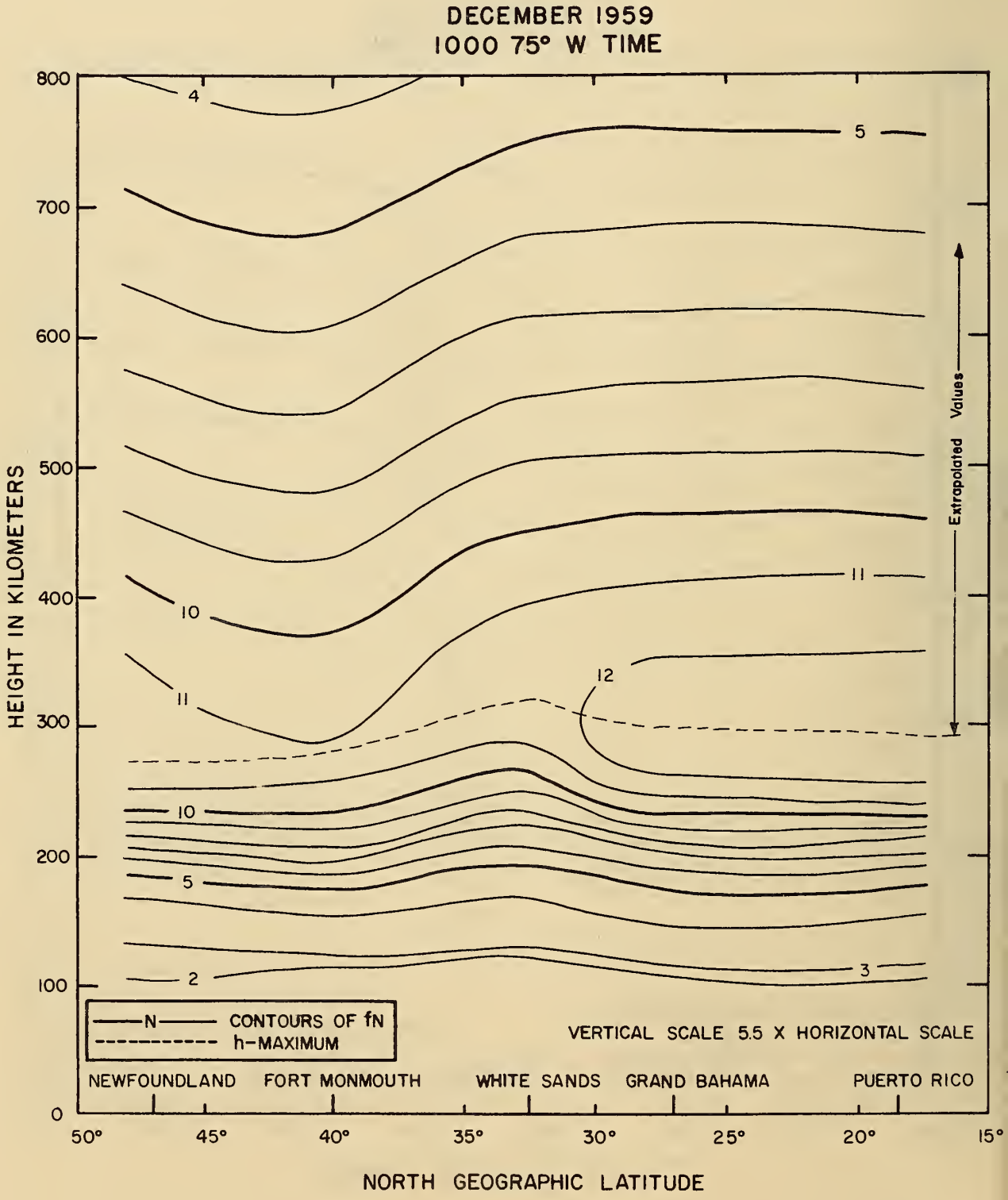
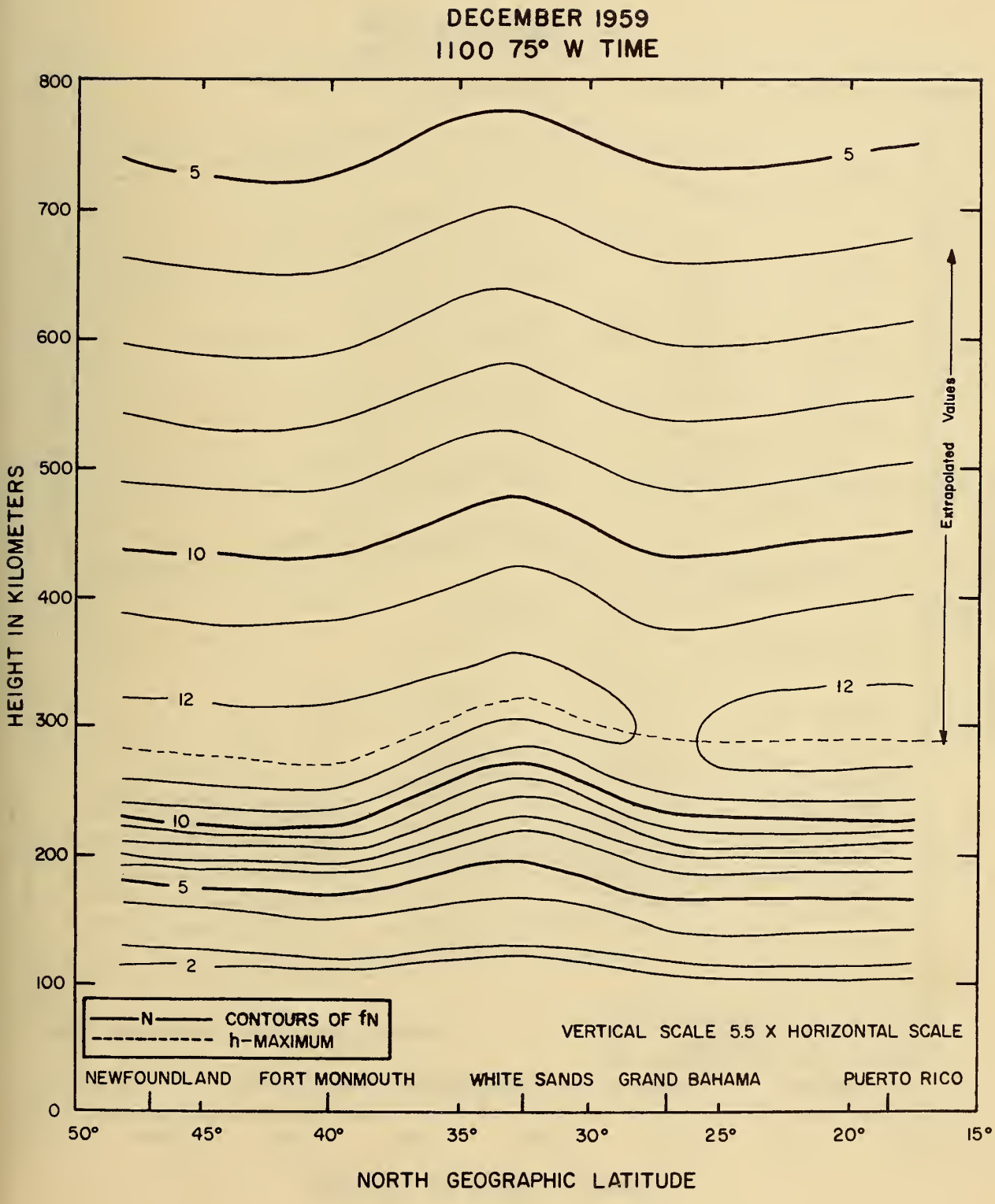
700
600
500
400
300
200
100
0
4
5
9
10
11
9
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
11
12
2
3
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
5
10
12
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
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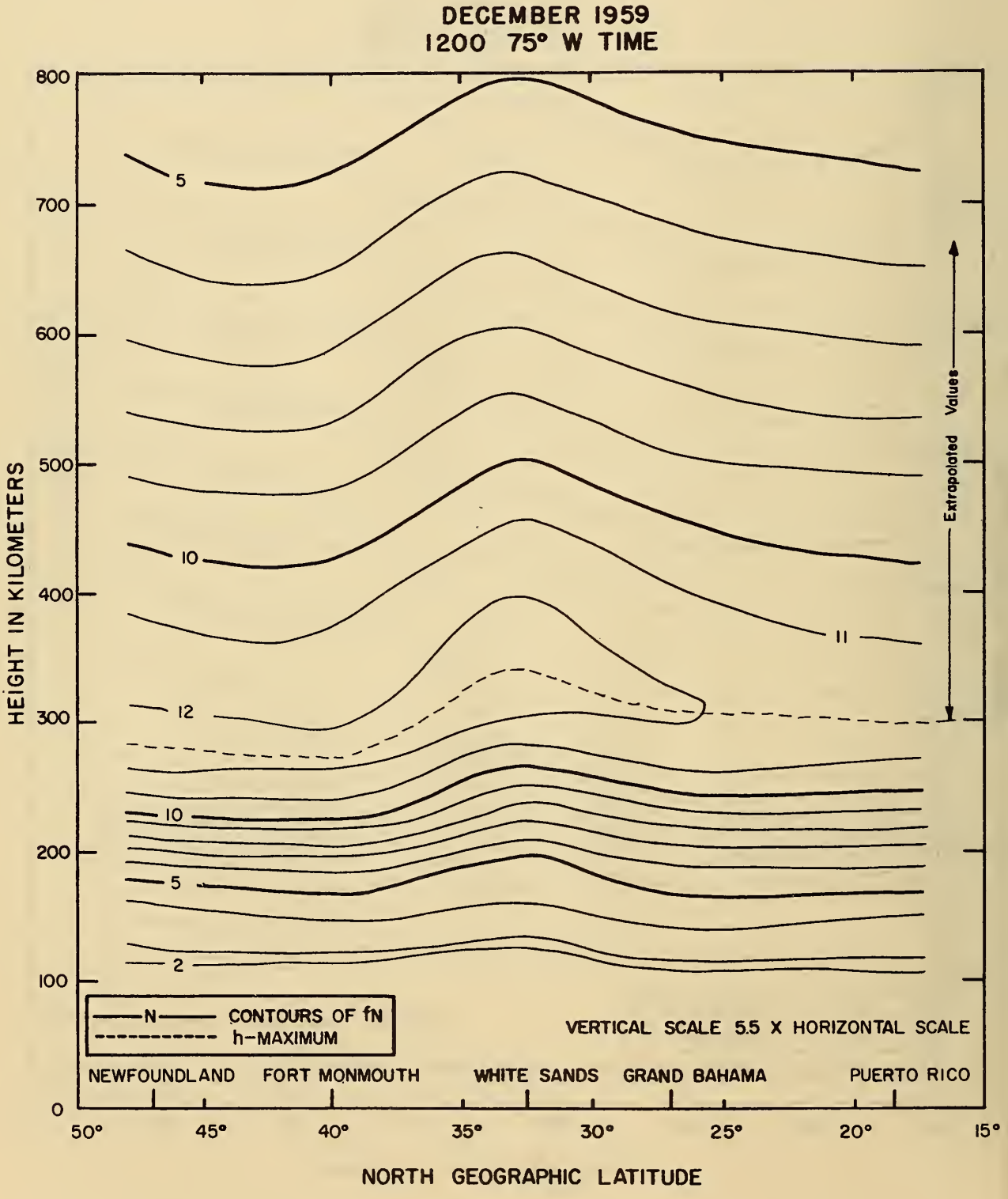
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1200 75° W TIME
HEIGHT IN KILOMETERS
800
700
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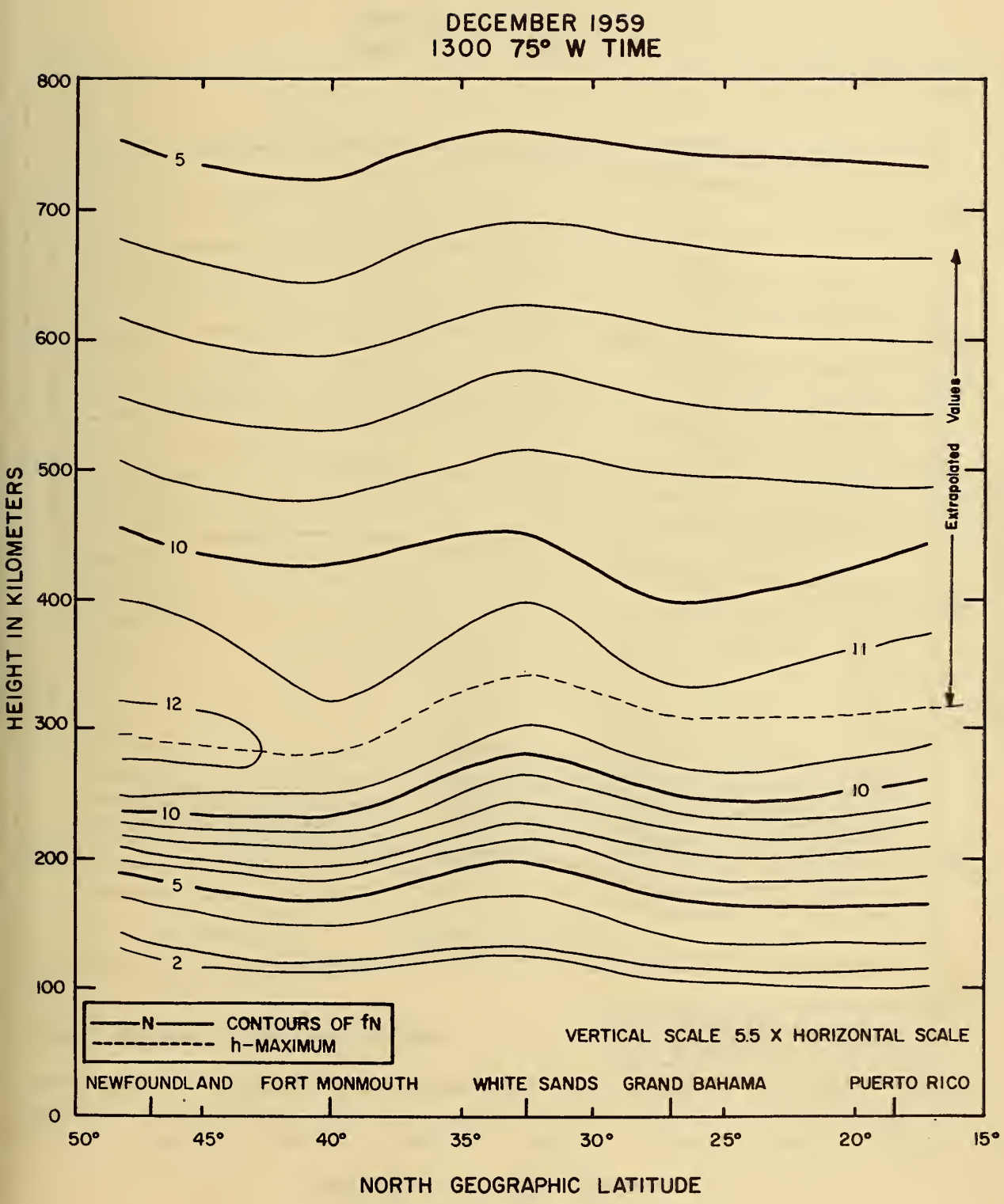
500
400
300
200
100
0
5
10
12
11
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1300 75° W TIME
HEIGHT IN KILOMETERS
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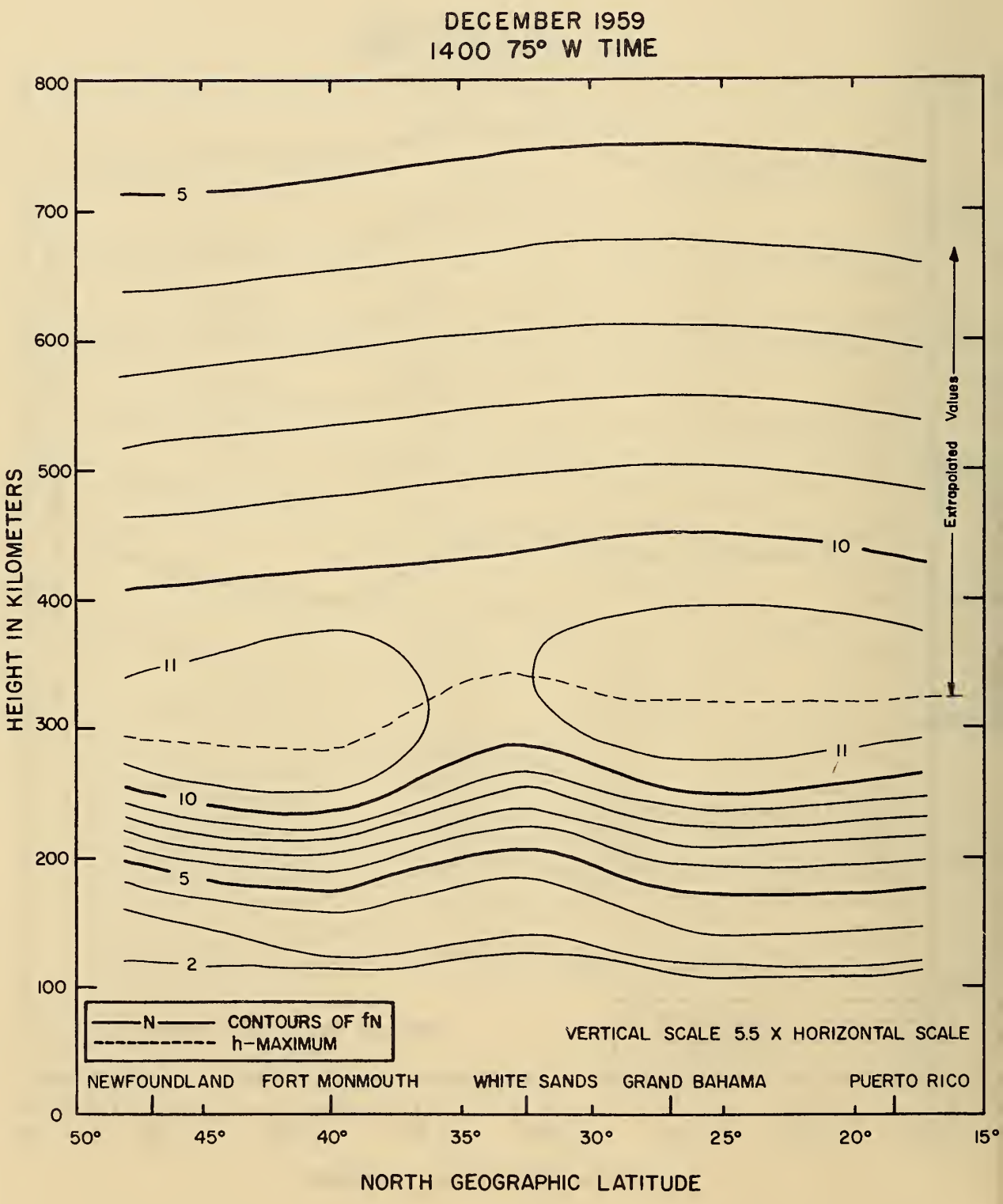
700
600
500
400
300
200
100
0
5
10
12
11
10
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1400 75° W TIME
HEIGHT IN KILOMETERS
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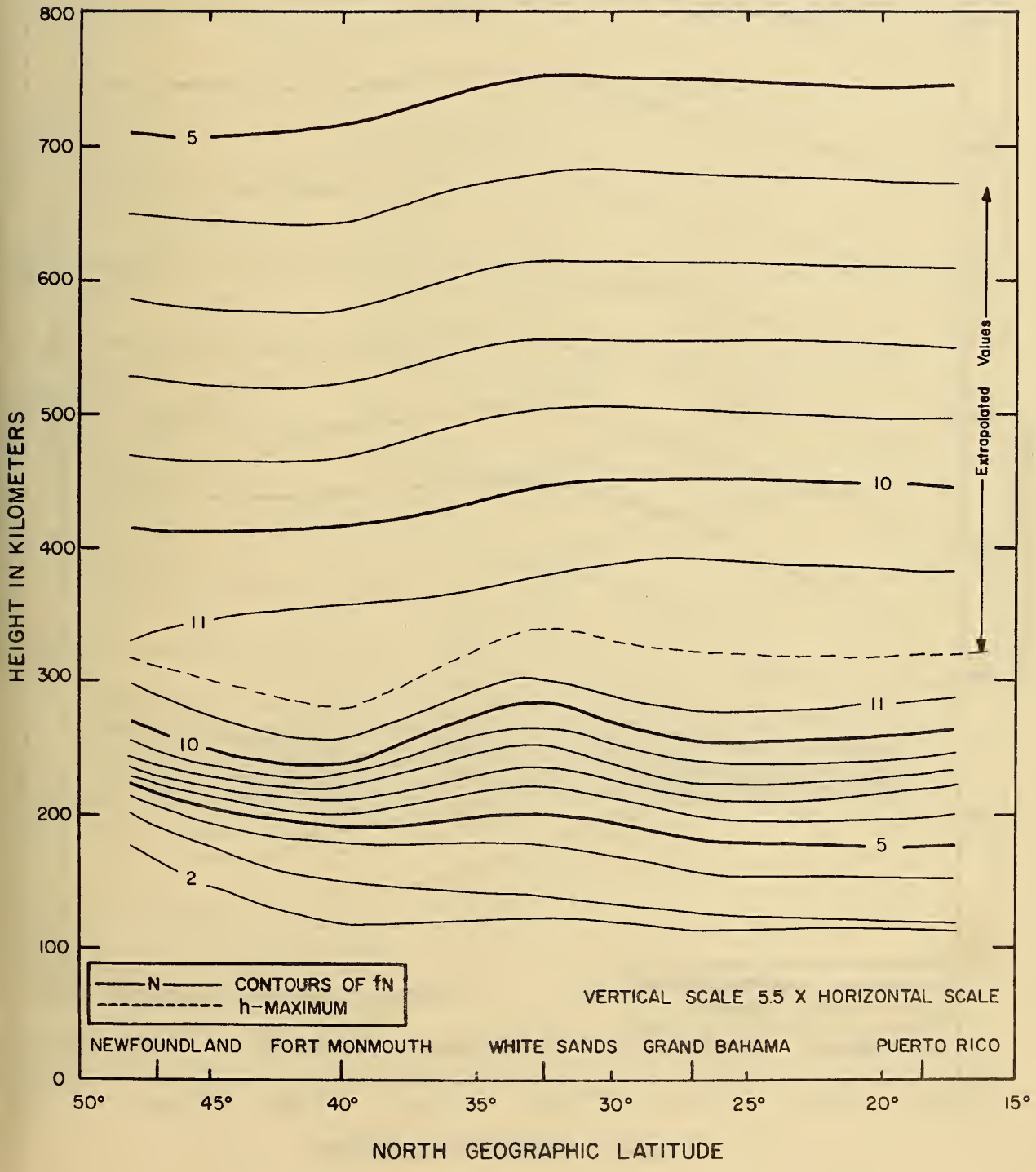
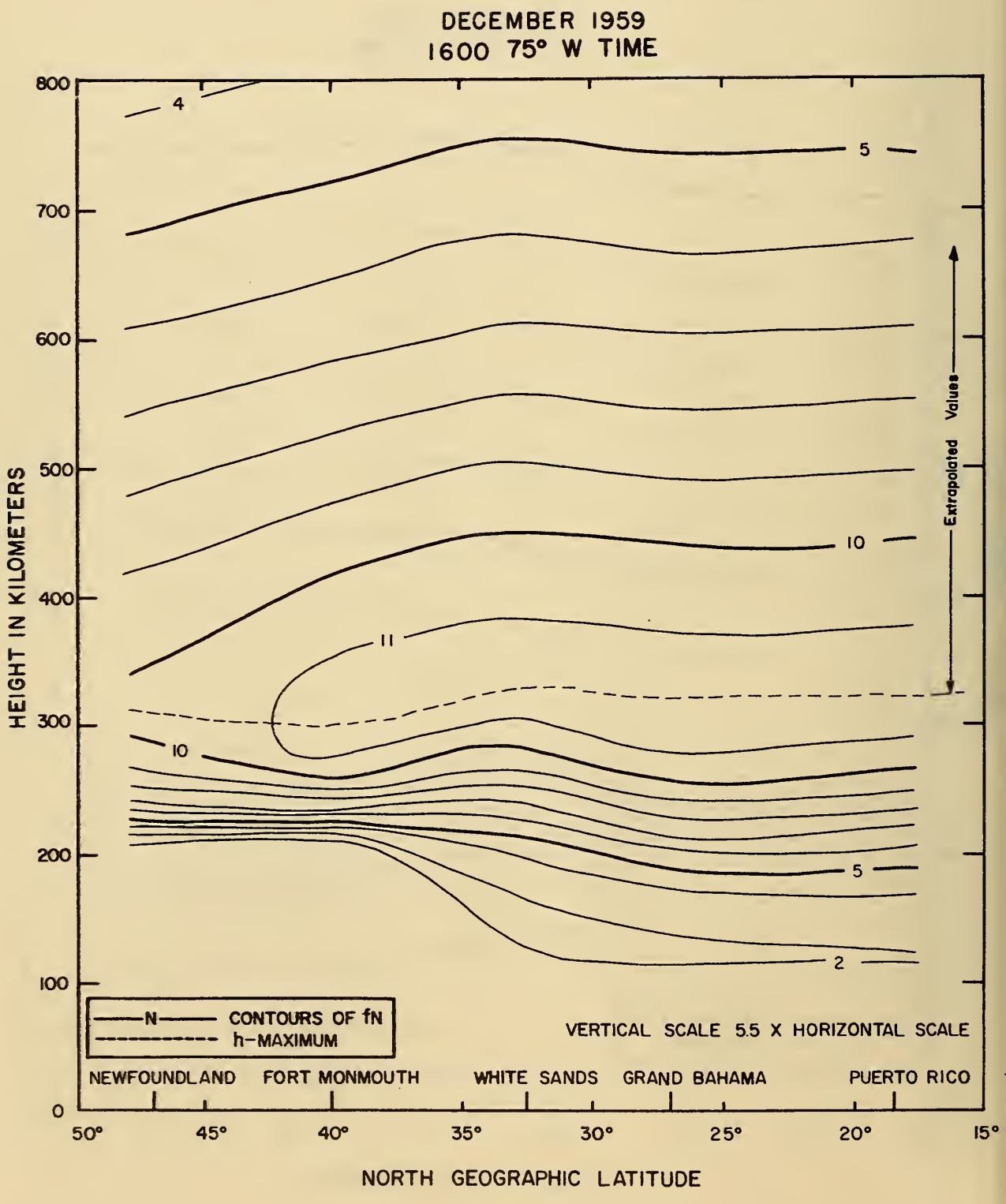
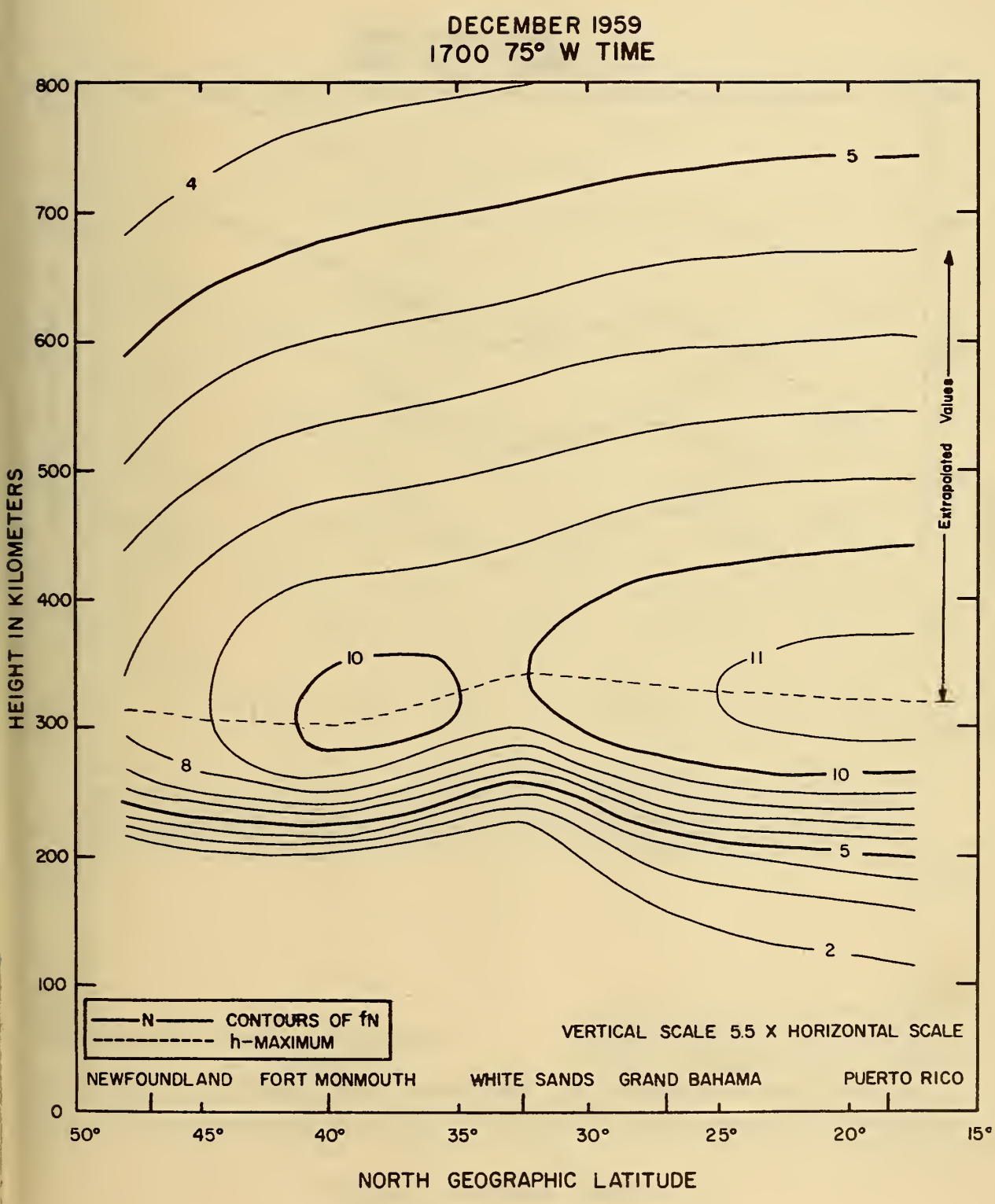
700
600
500
400
300
200
100
0
5
10
11
11
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

DECEMBER 1959
1500 75° W TIME




DECEMBER 1959
1600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
11
10
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1700 75° W TIME
HEIGHT IN KILOMETERS
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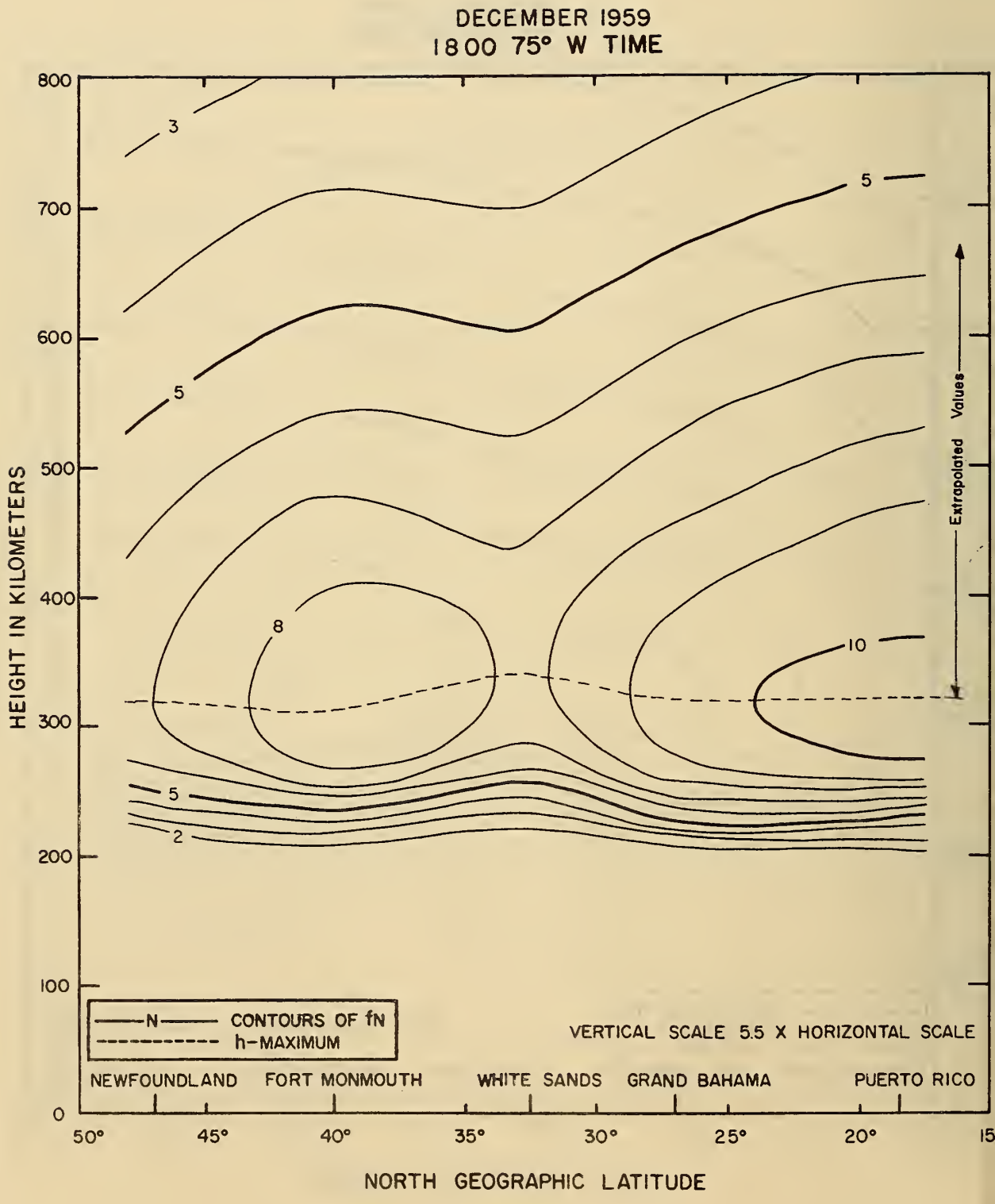
300
200
100
0
4
5
10
11
8
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1800 75° W TIME
HEIGHT IN KILOMETERS
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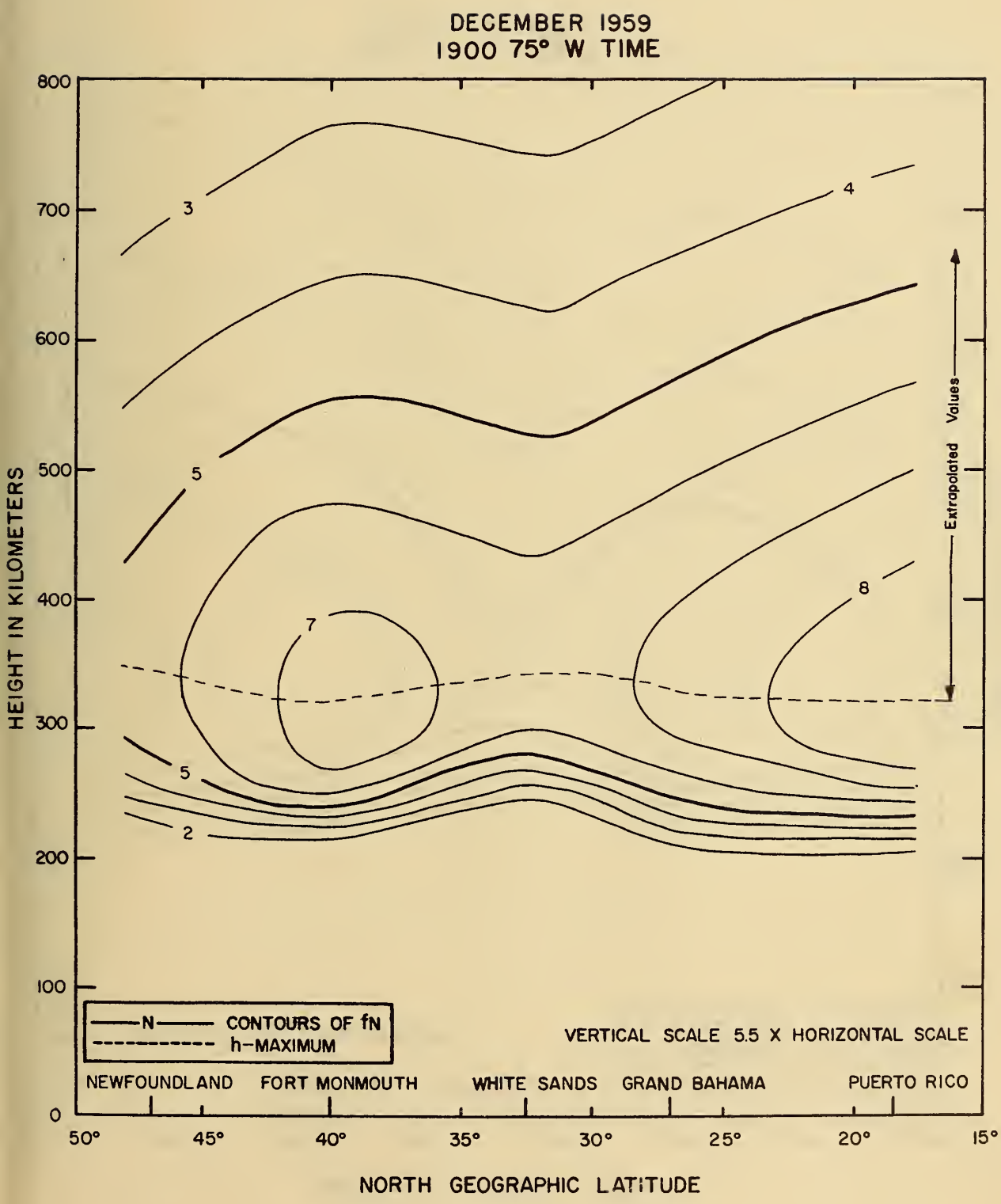
700
600
500
400
300
200
100
0
3
5
5
8
10
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
1900 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
4
5
7
8
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
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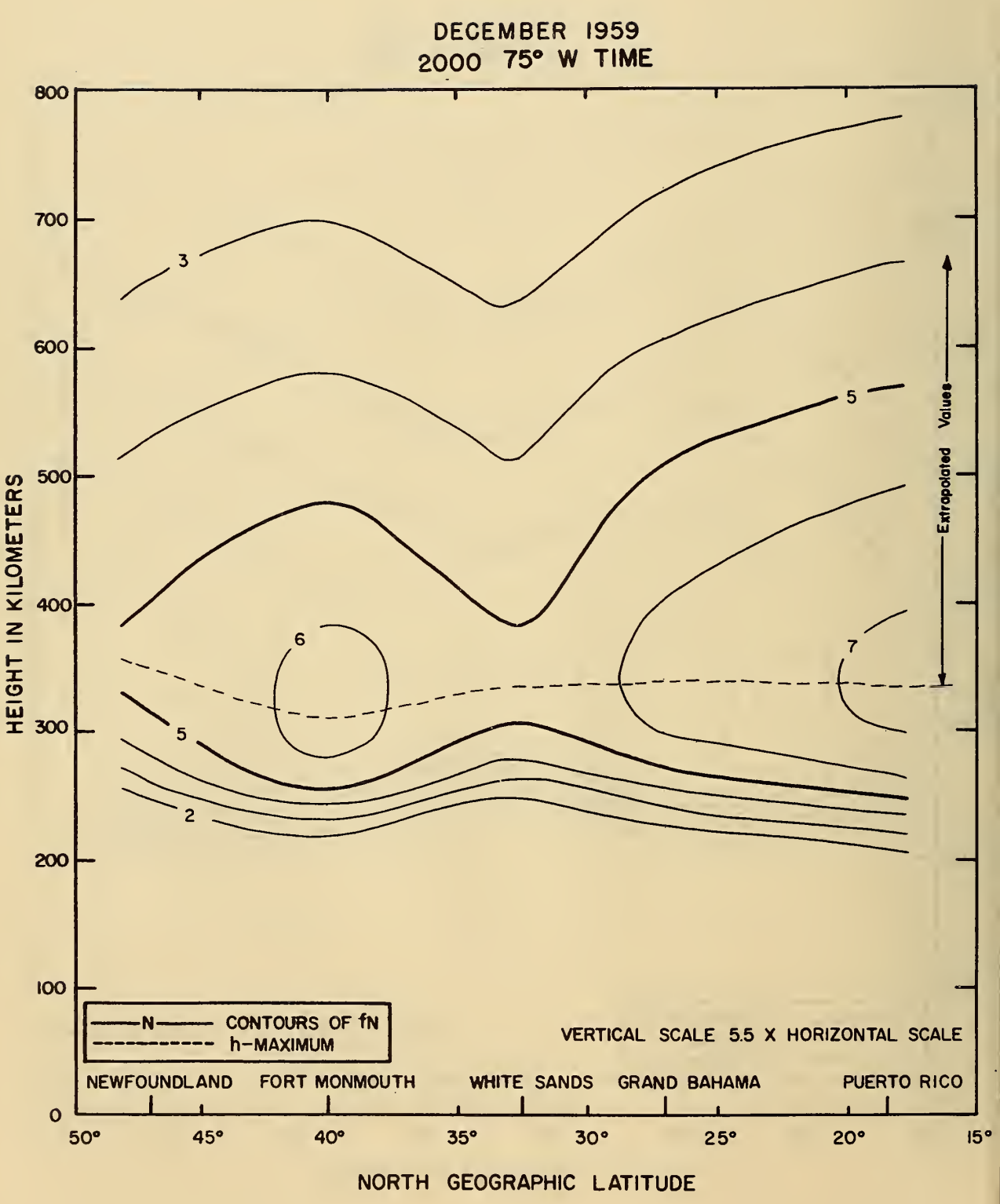
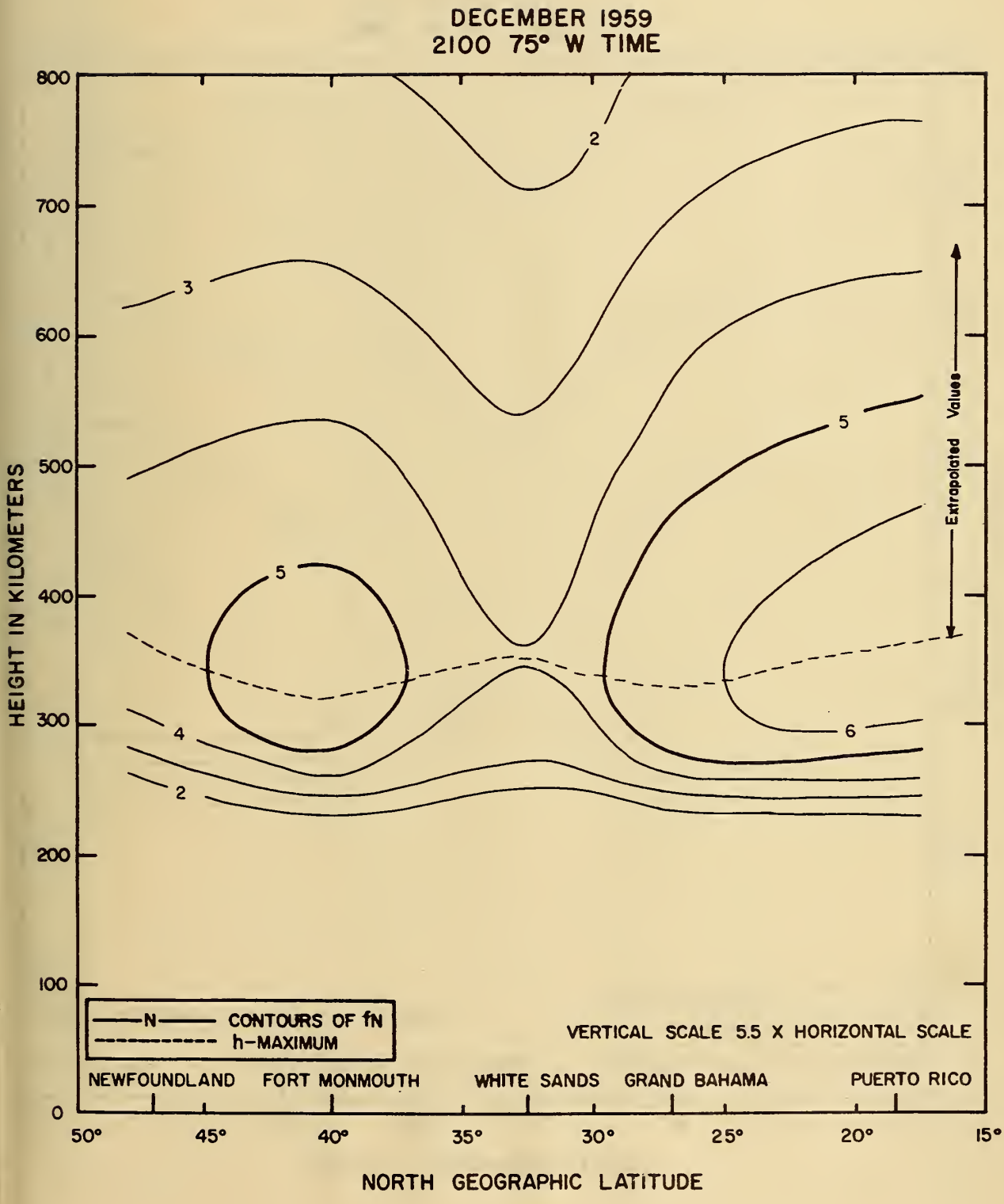
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
2000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
6
7
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


DECEMBER 1959
2100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
3
5
5
4
2
6
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
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25°
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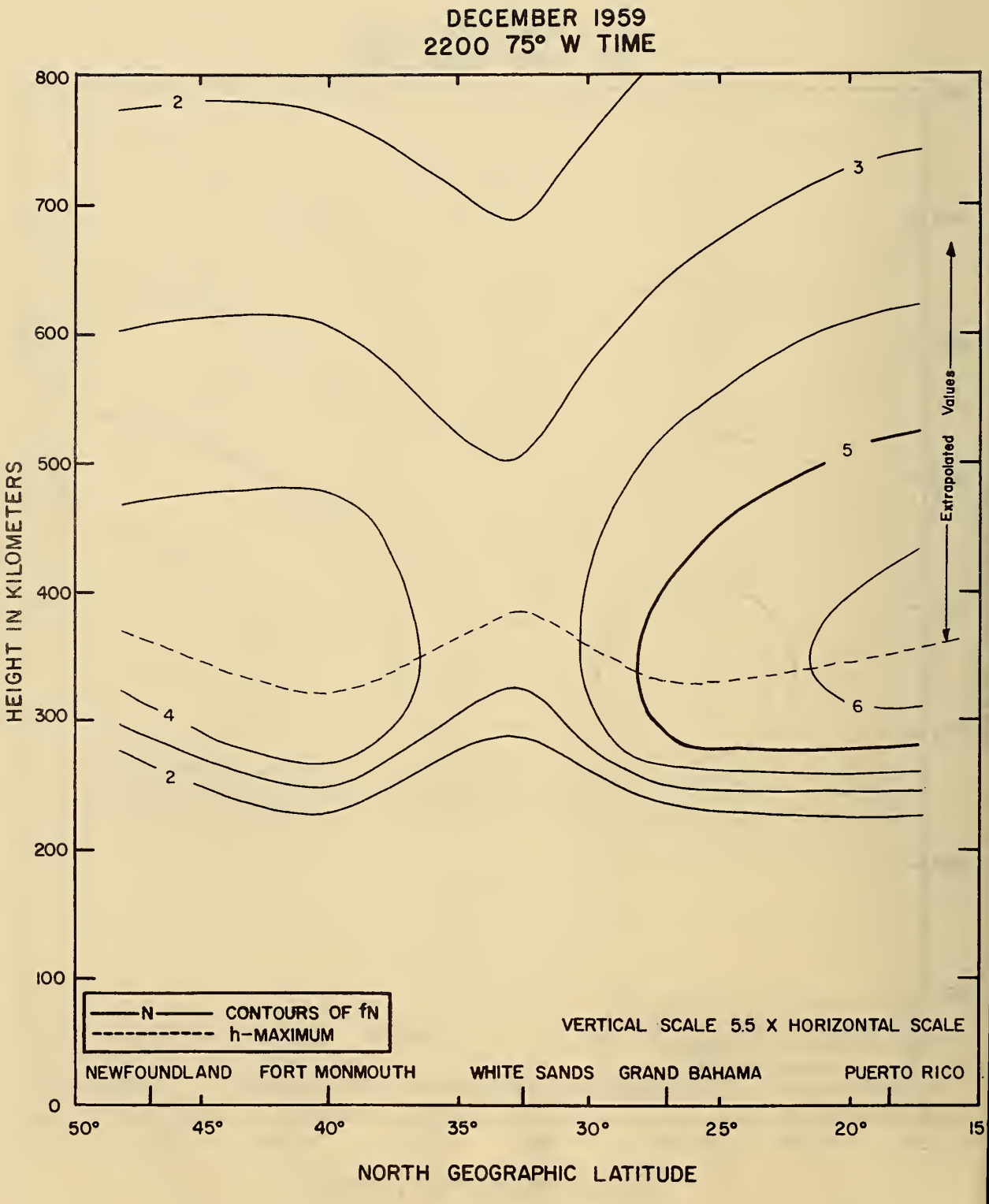
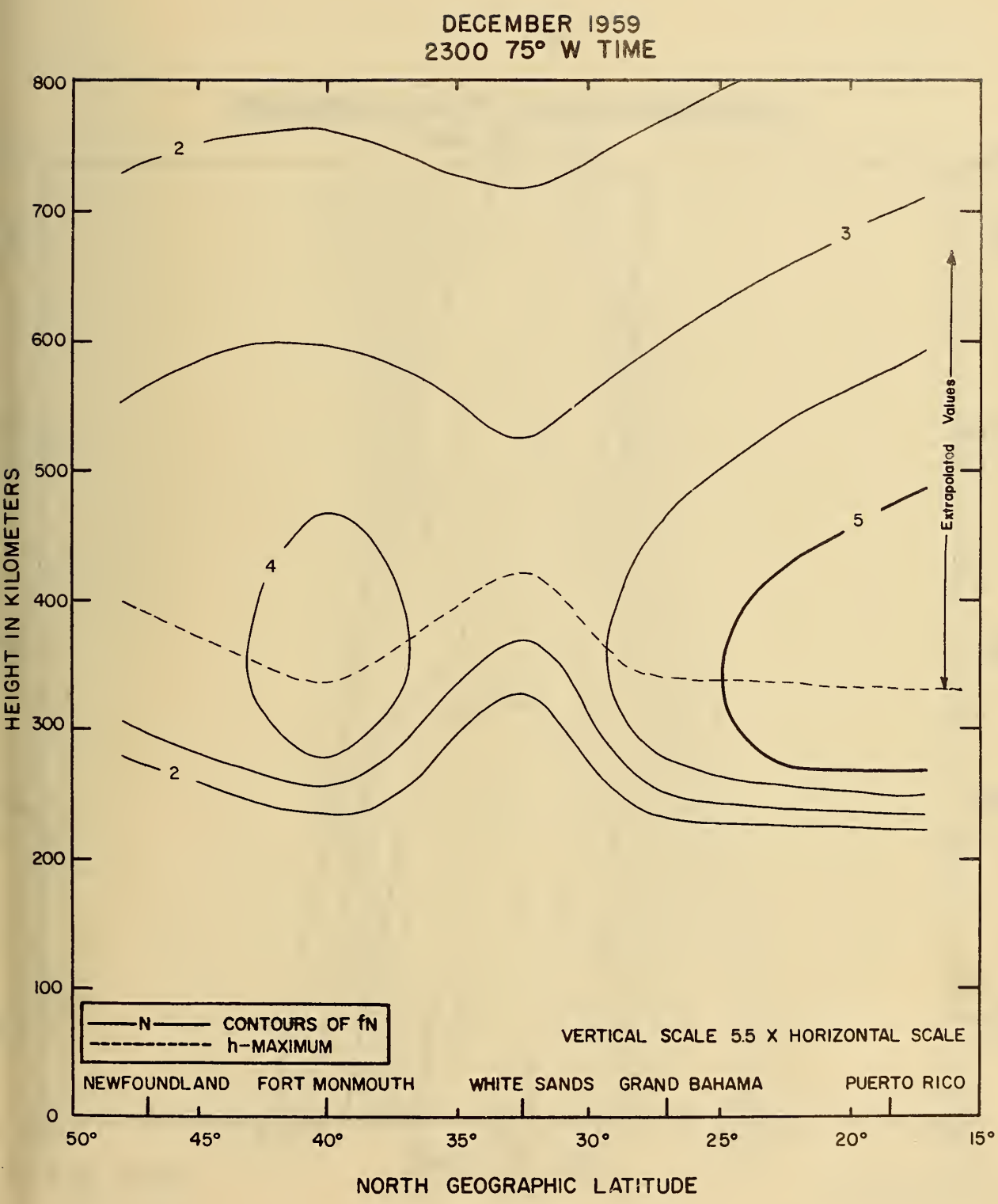
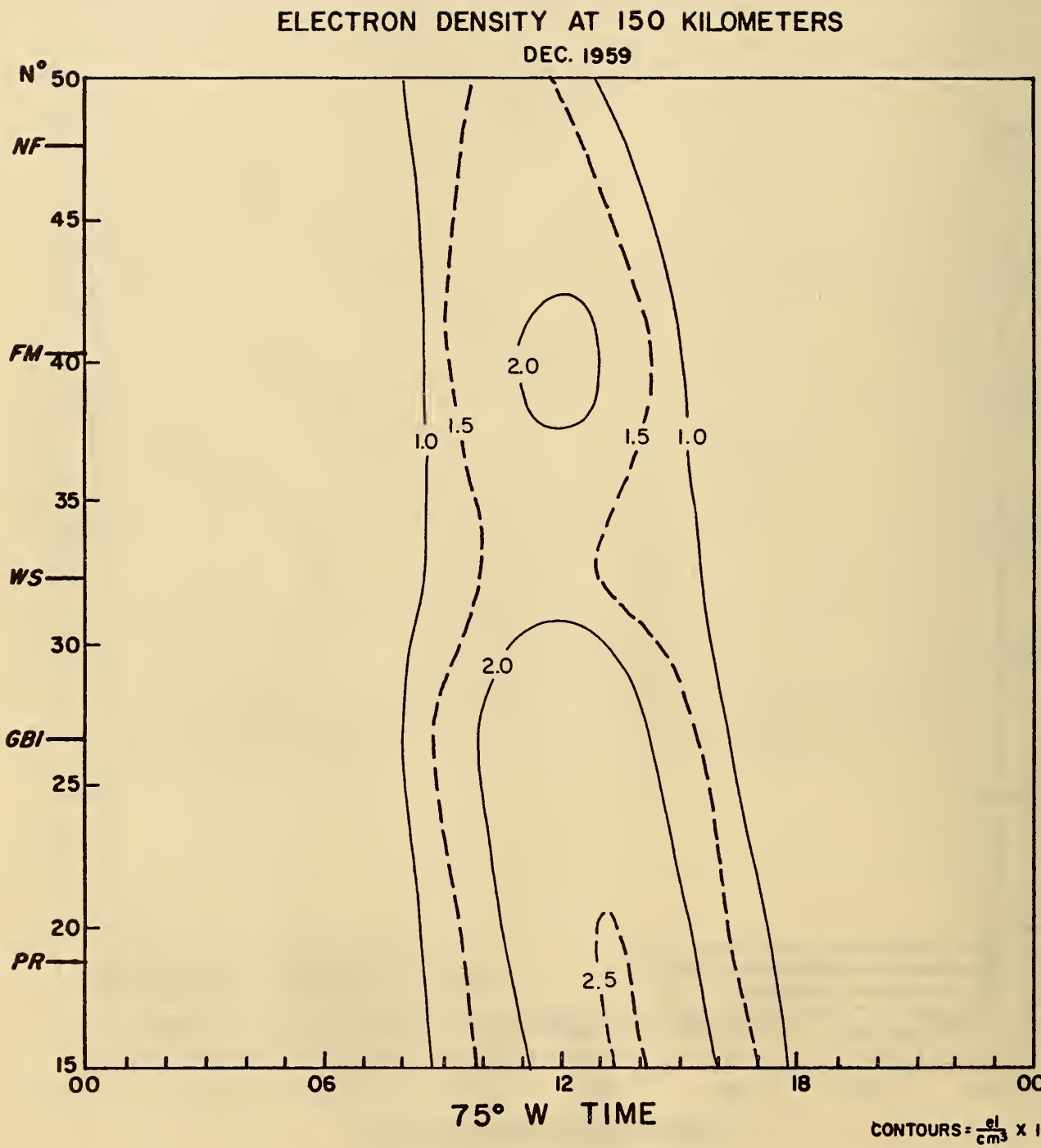
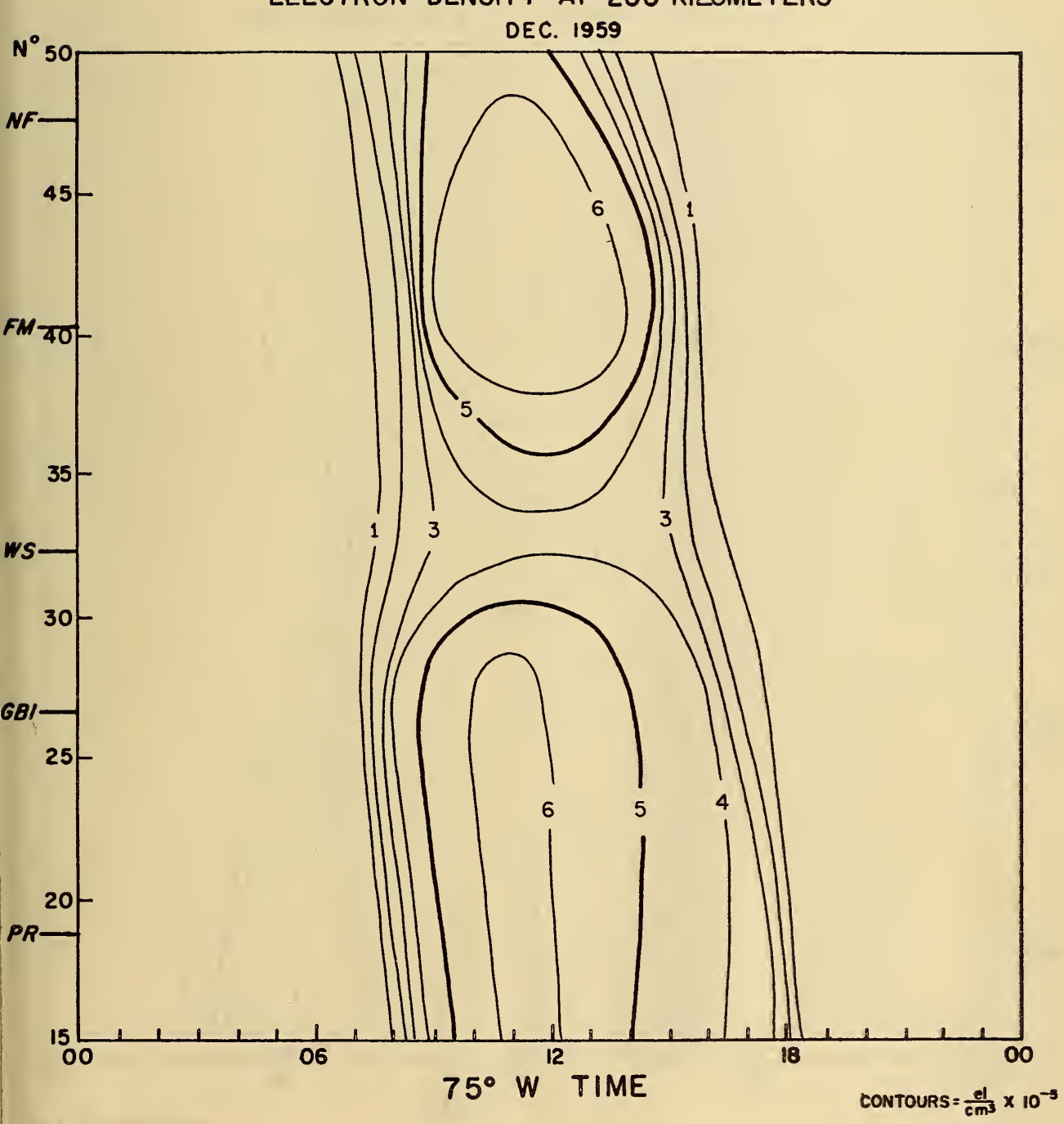
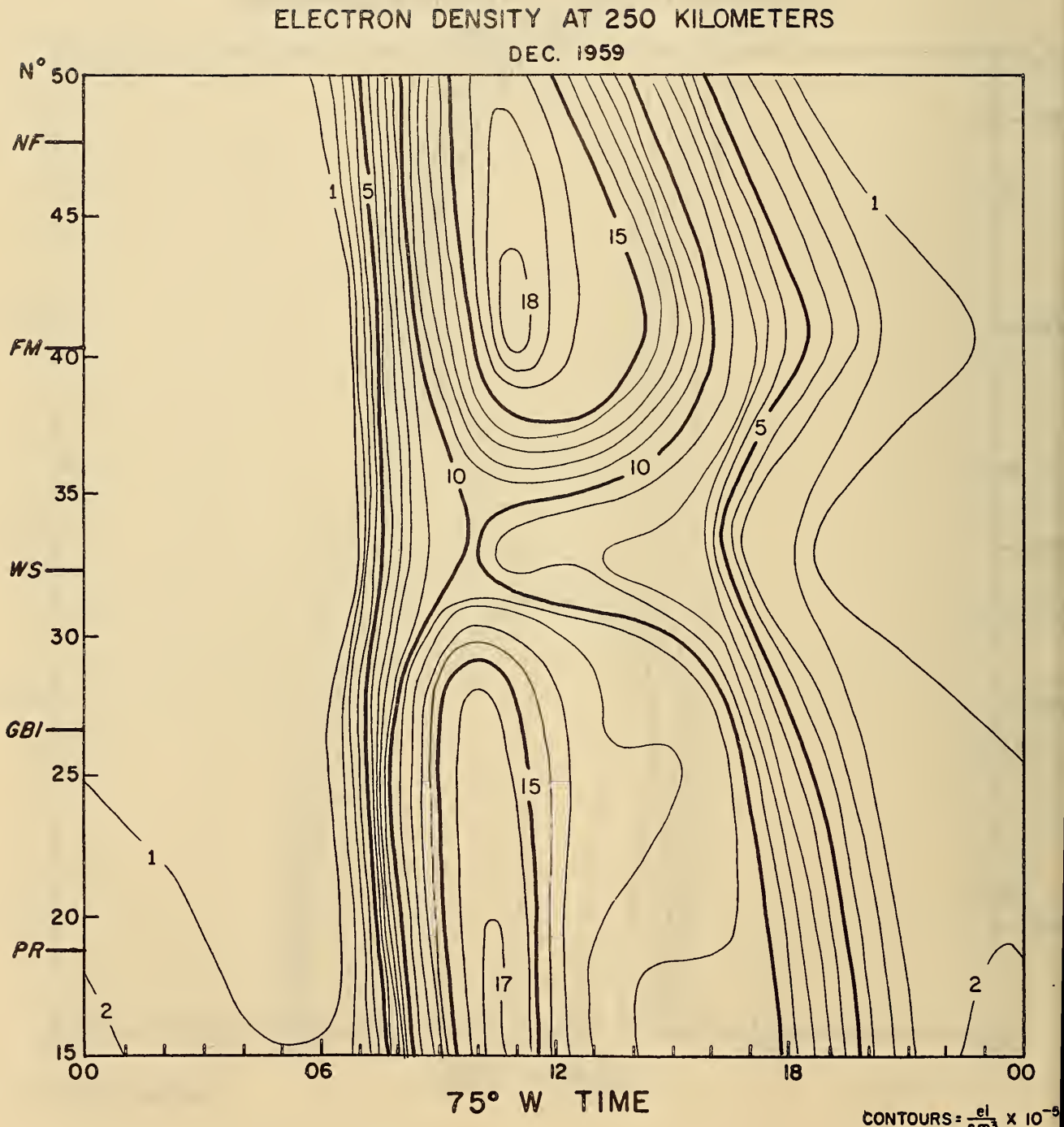
15°
NORTH GEOGRAPHIC LATITUDE

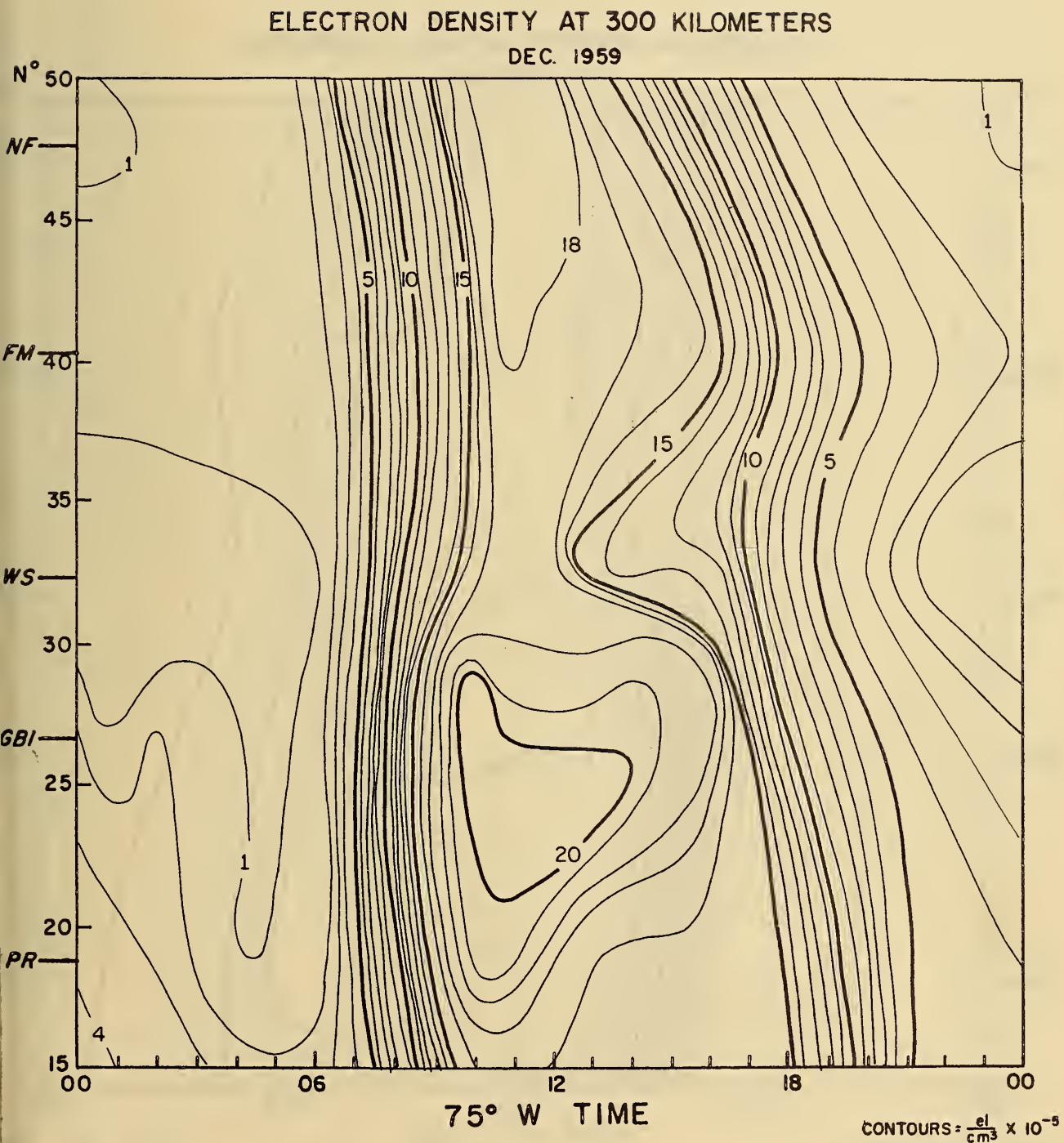

DECEMBER 1959
2200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
3
5
6
4
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15
NORTH GEOGRAPHIC LATITUDE

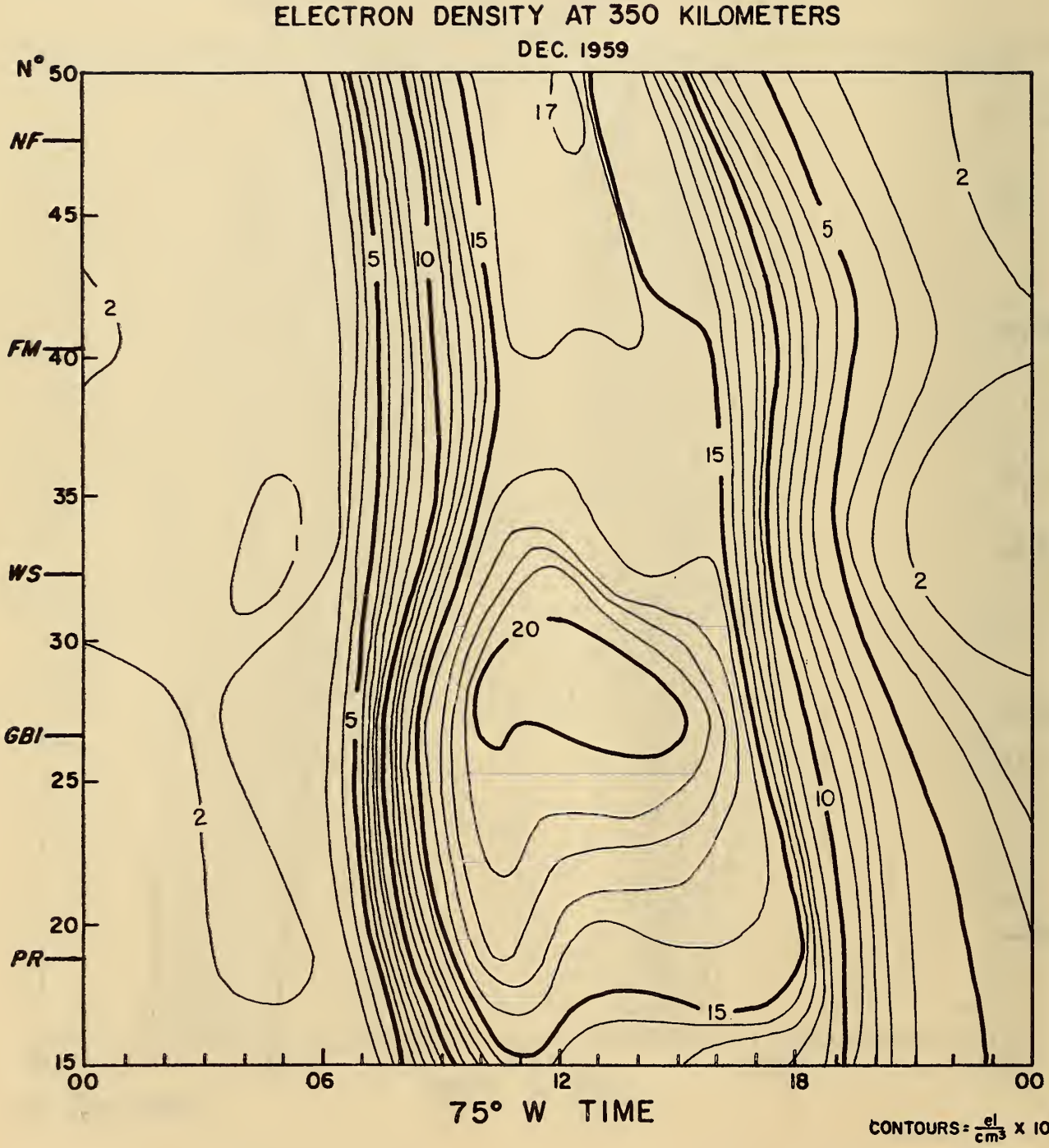

DECEMBER 1959
2300 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
3
4
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

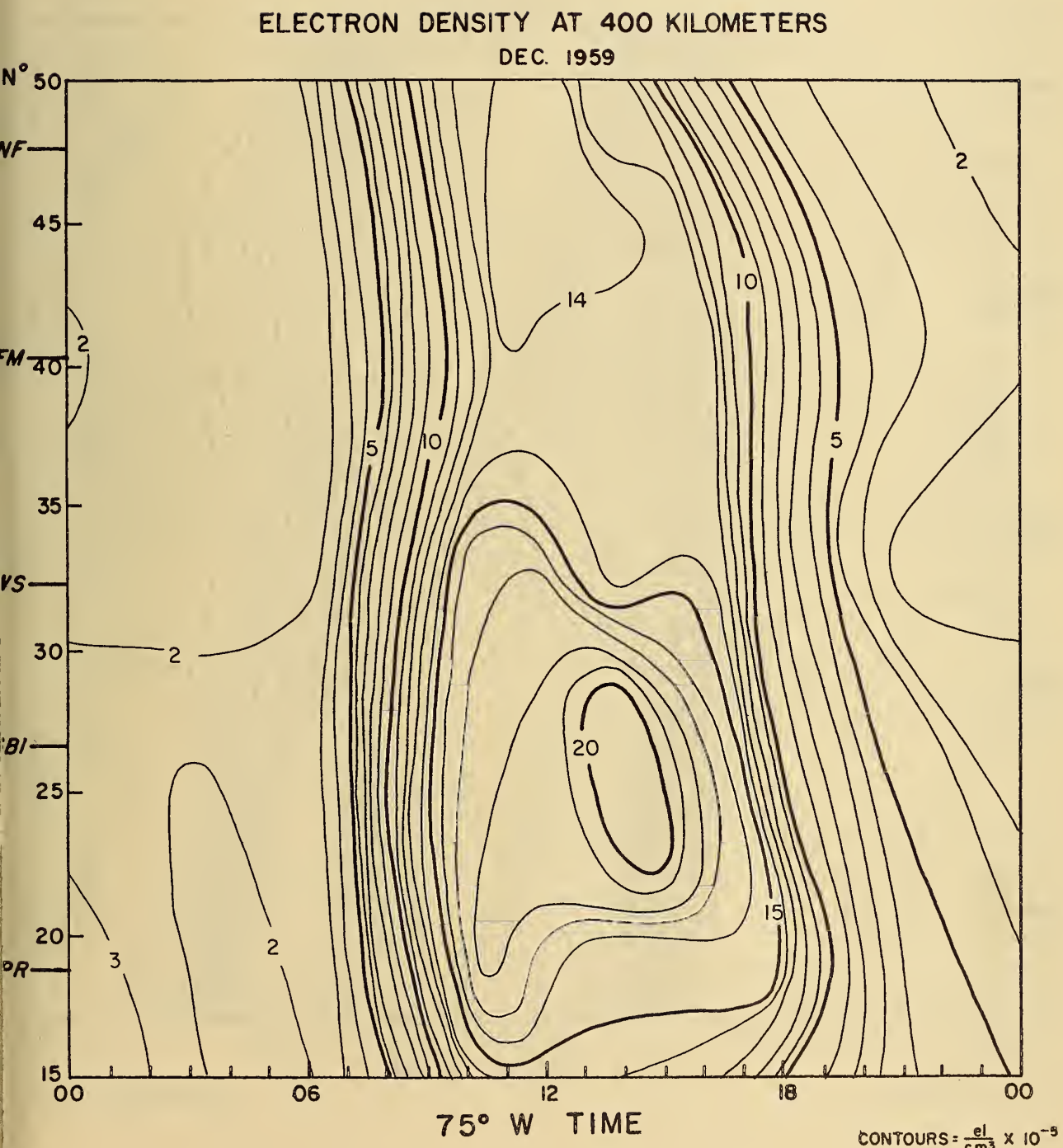

ELECTRON DENSITY AT 150 KILOMETERS
DEC. 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
1.0
1.5
2.0
1.5
1.0
2.0
2.5
00
06
12
18
00
75° W TIME
CONTOURS = el/cm3 X 10-5


ELECTRON DENSITY AT 200 KILOMETERS
DEC. 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
6
1
5
1
3
3
6
5
4
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ x 10⁻⁵

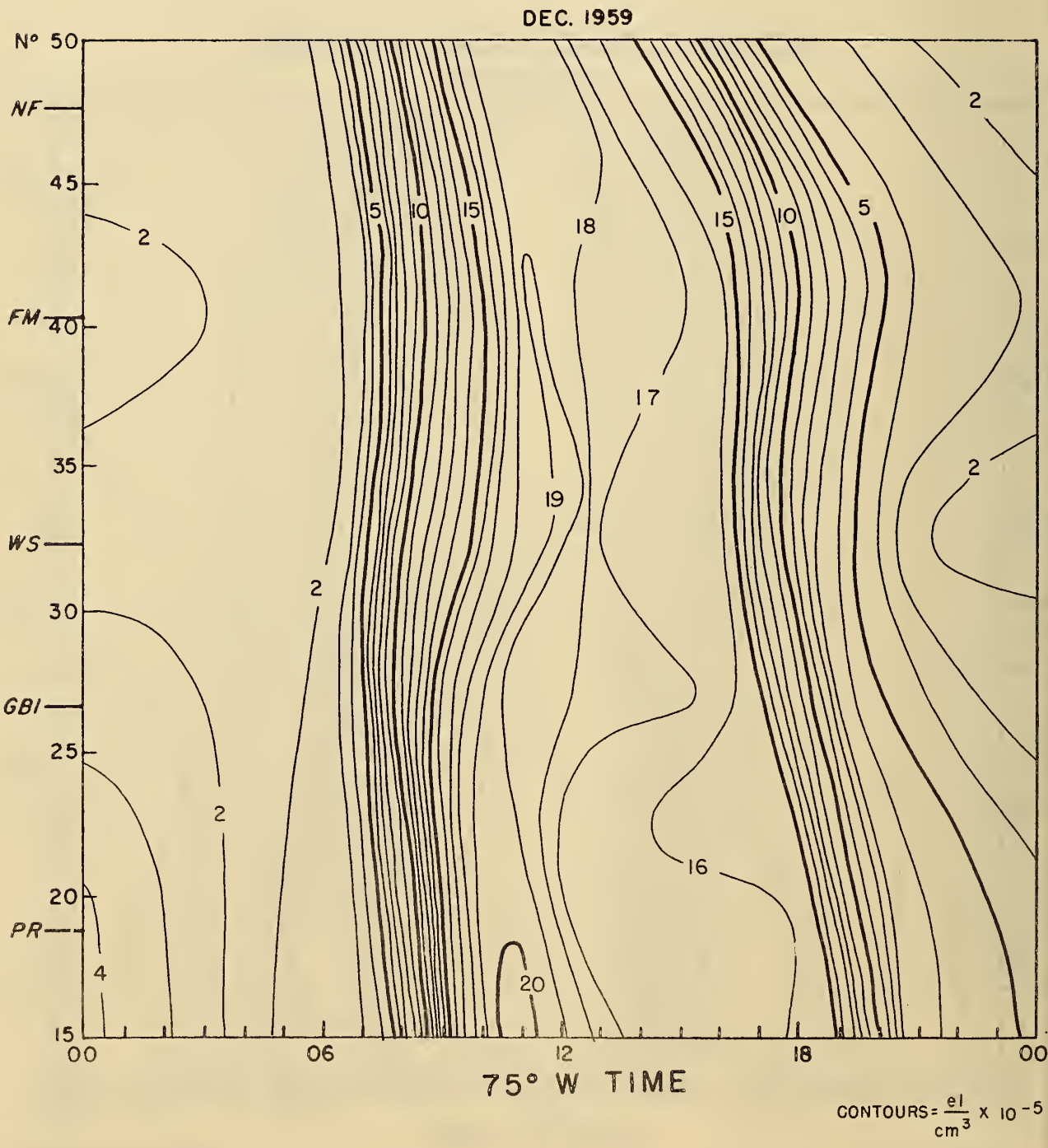

ELECTRON DENSITY AT 250 KILOMETERS
DEC. 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ X 10⁻⁵
1
5
15
18
10
10
5
1
15
1
17
2
2


ELECTRON DENSITY AT 300 KILOMETERS
DEC. 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ X 10⁻⁵
1
5
10
15
18
20
4

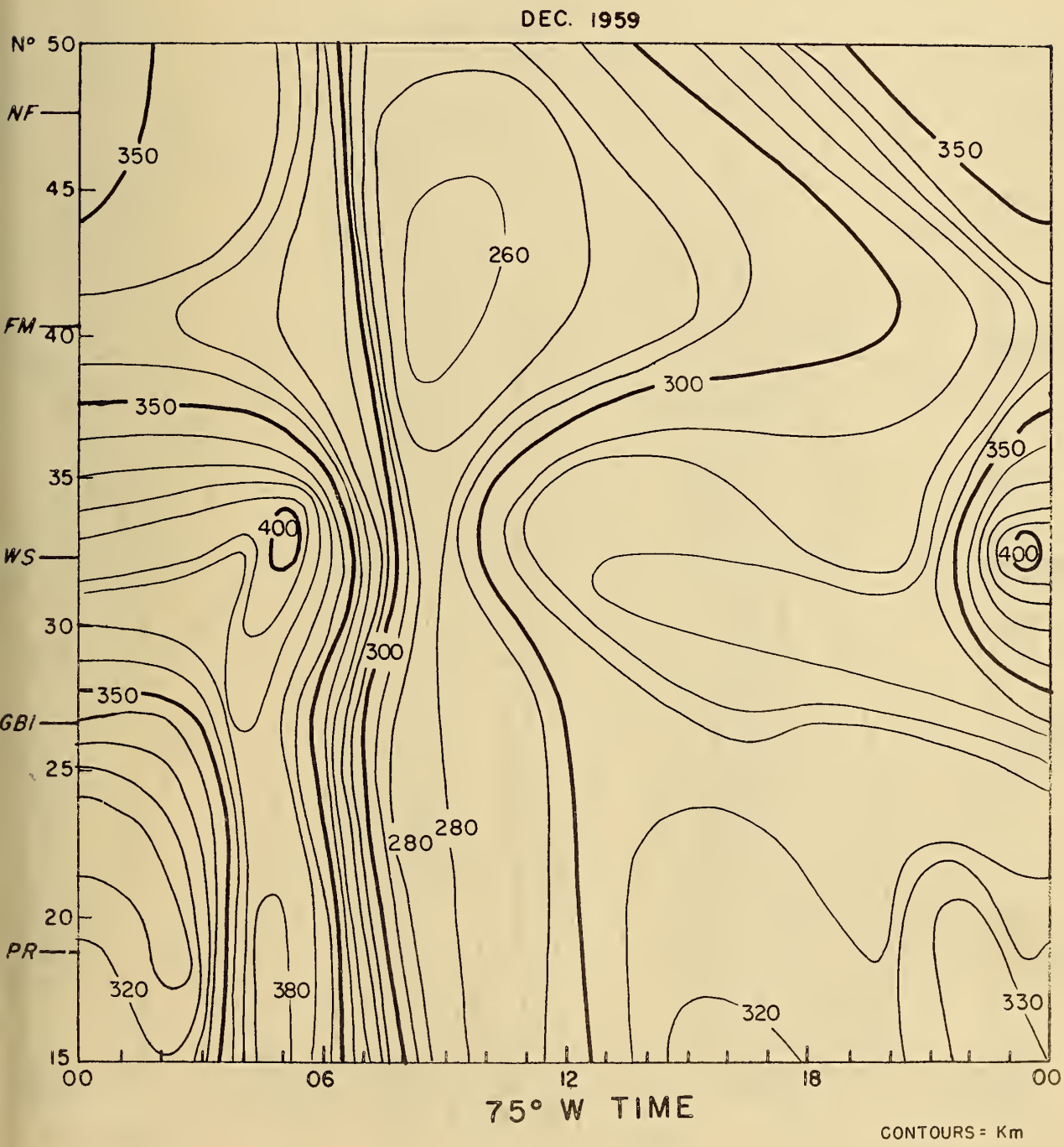

ELECTRON DENSITY AT 350 KILOMETERS
DEC. 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ X 10⁻⁵
1
2
5
10
15
17
20


ELECTRON DENSITY AT 400 KILOMETERS
DEC. 1959
N° 50
NF
45
FM
40
35
VS
30
BI
25
20
R
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ X 10⁻⁵
2
5
10
14
10
5
2
2
20
15
3
2

MAXIMUM ELECTRON DENSITY
NMAX



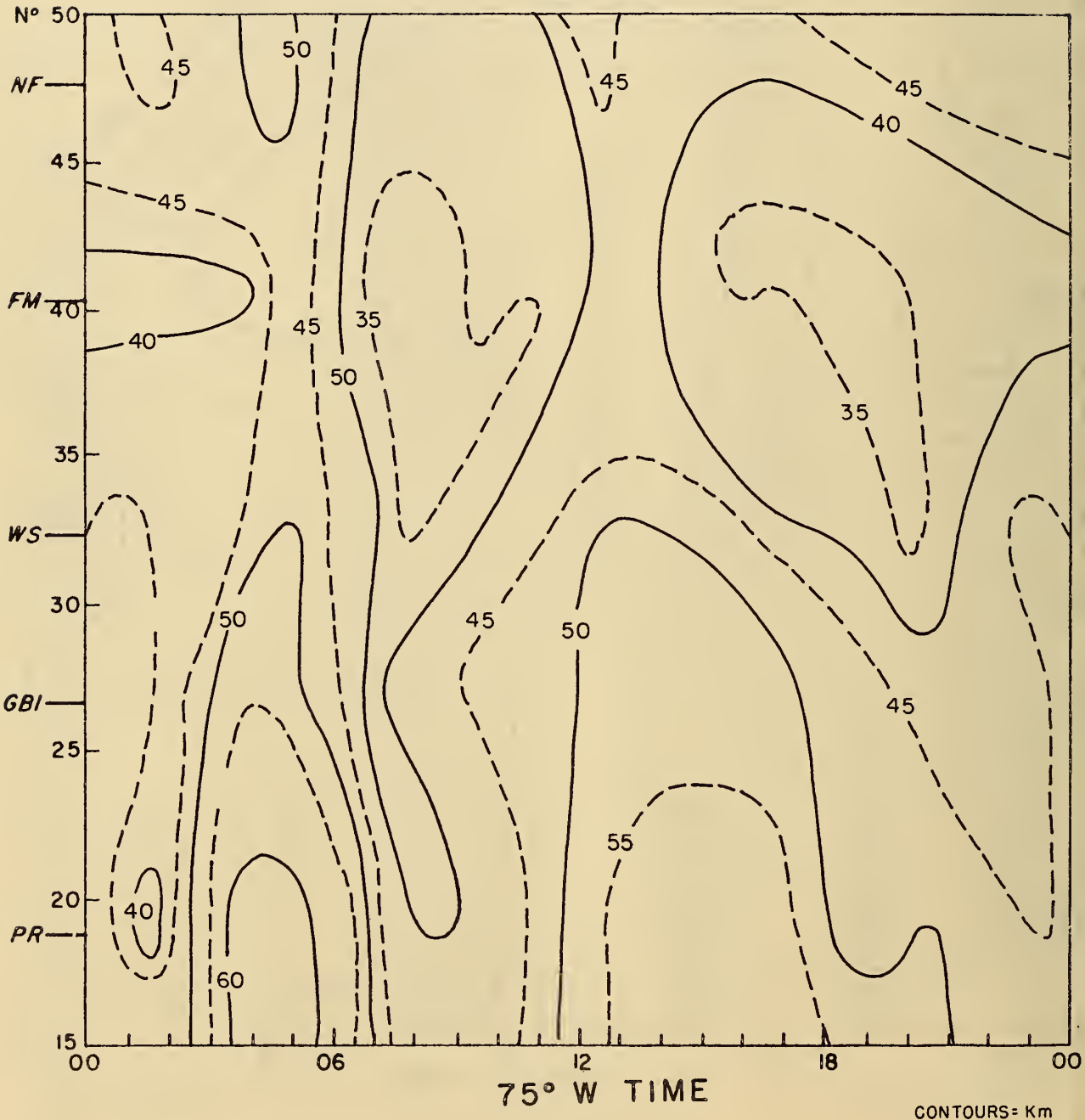
HEIGHT OF MAXIMUM ELECTRON DENSITY
HMAX



QUARTER THICKNESS OF F-REGION PEAK

SCAT

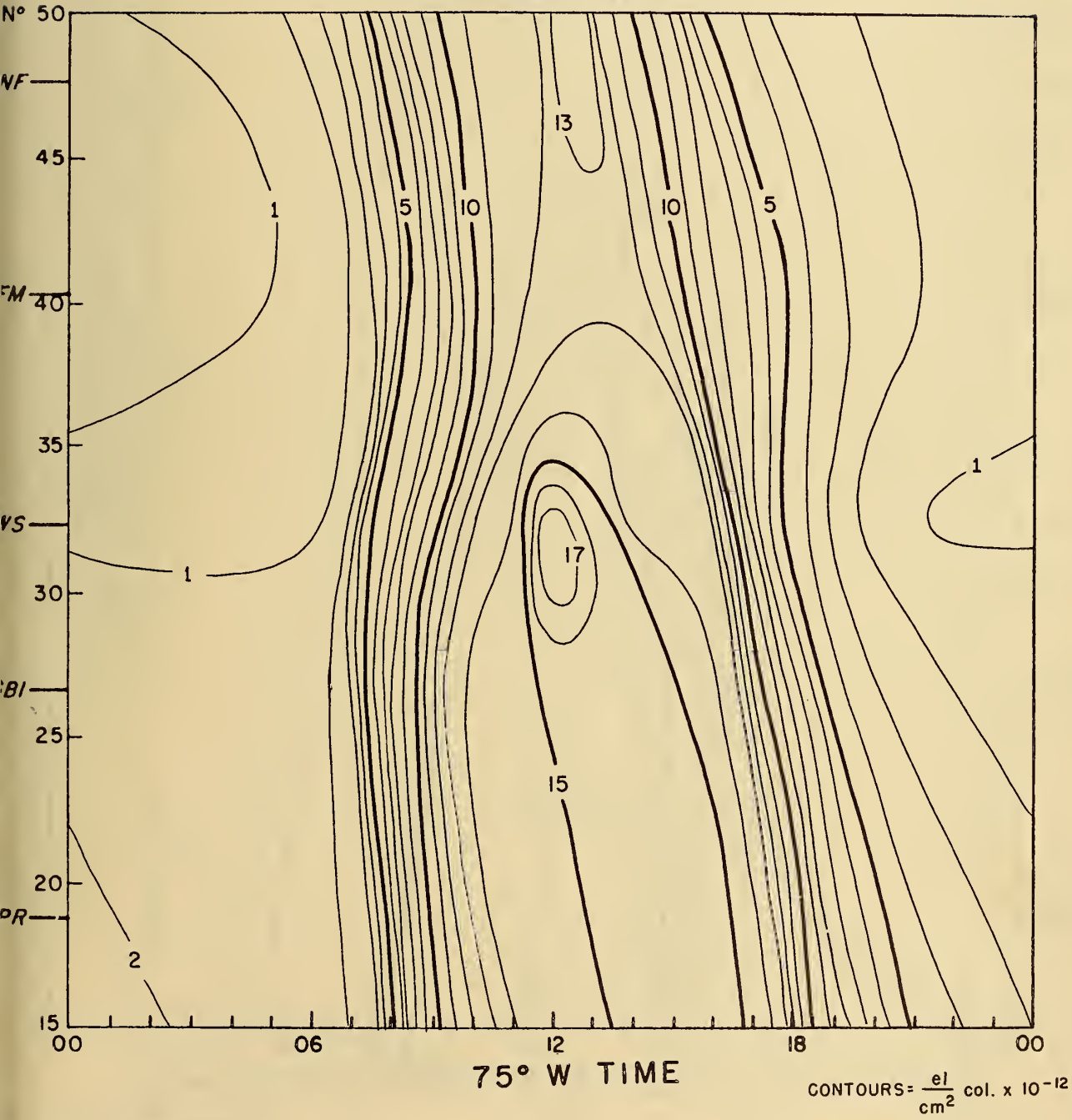
DEC. 1959



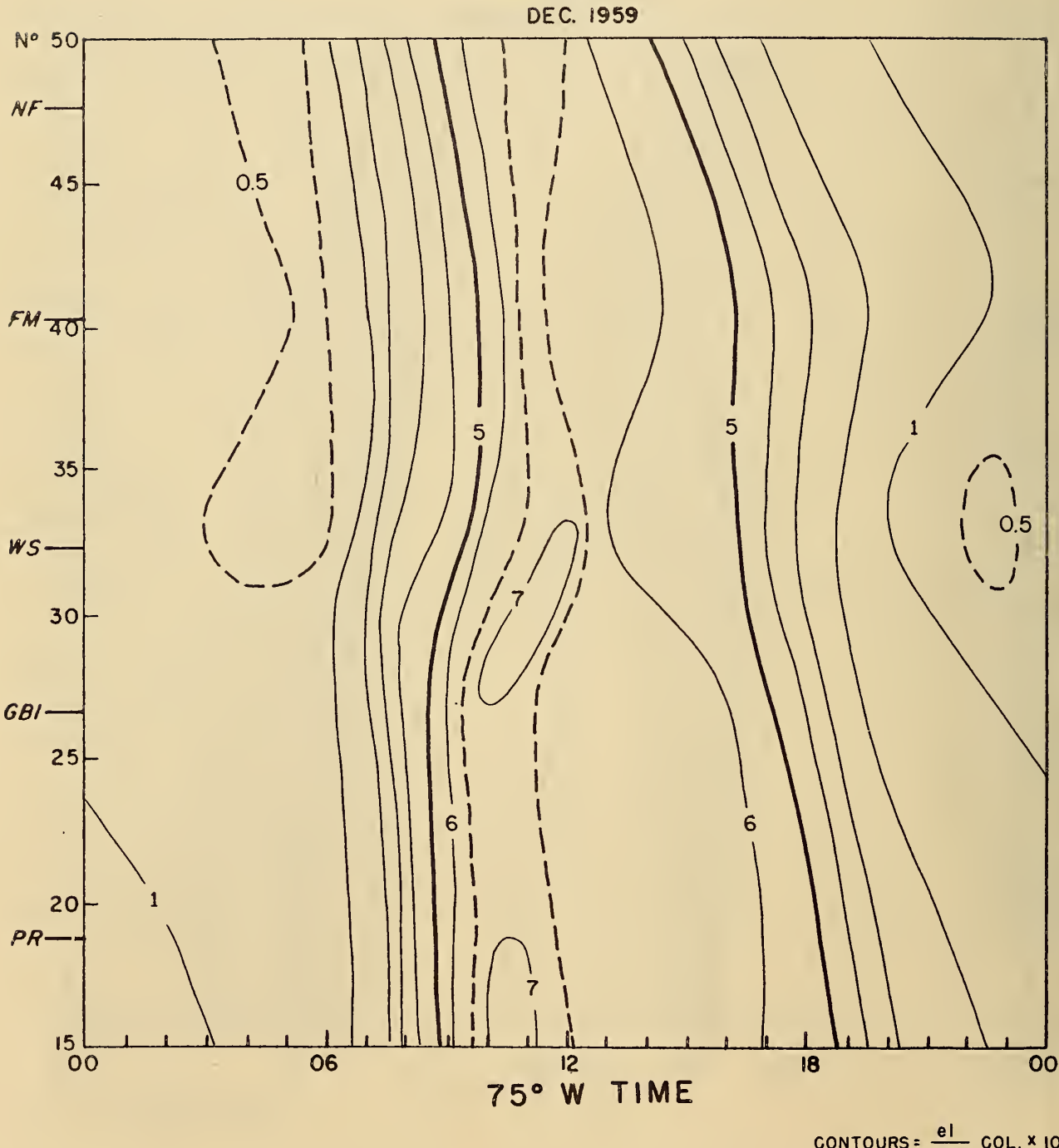
ELECTRON DENSITY INTEGRATED TO HEIGHT OF MAXIMUM ELECTRON DENSITY

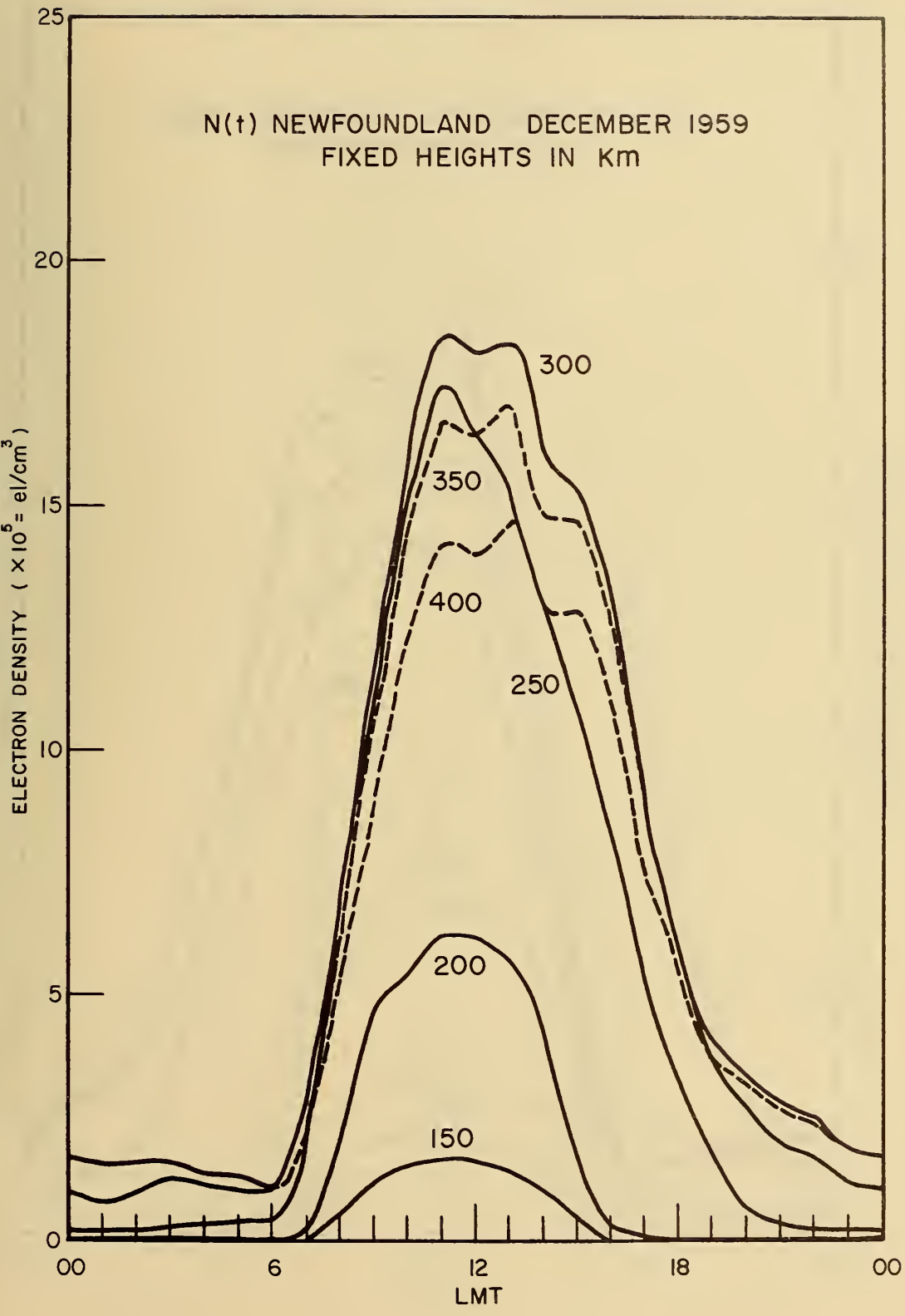
SHMAX

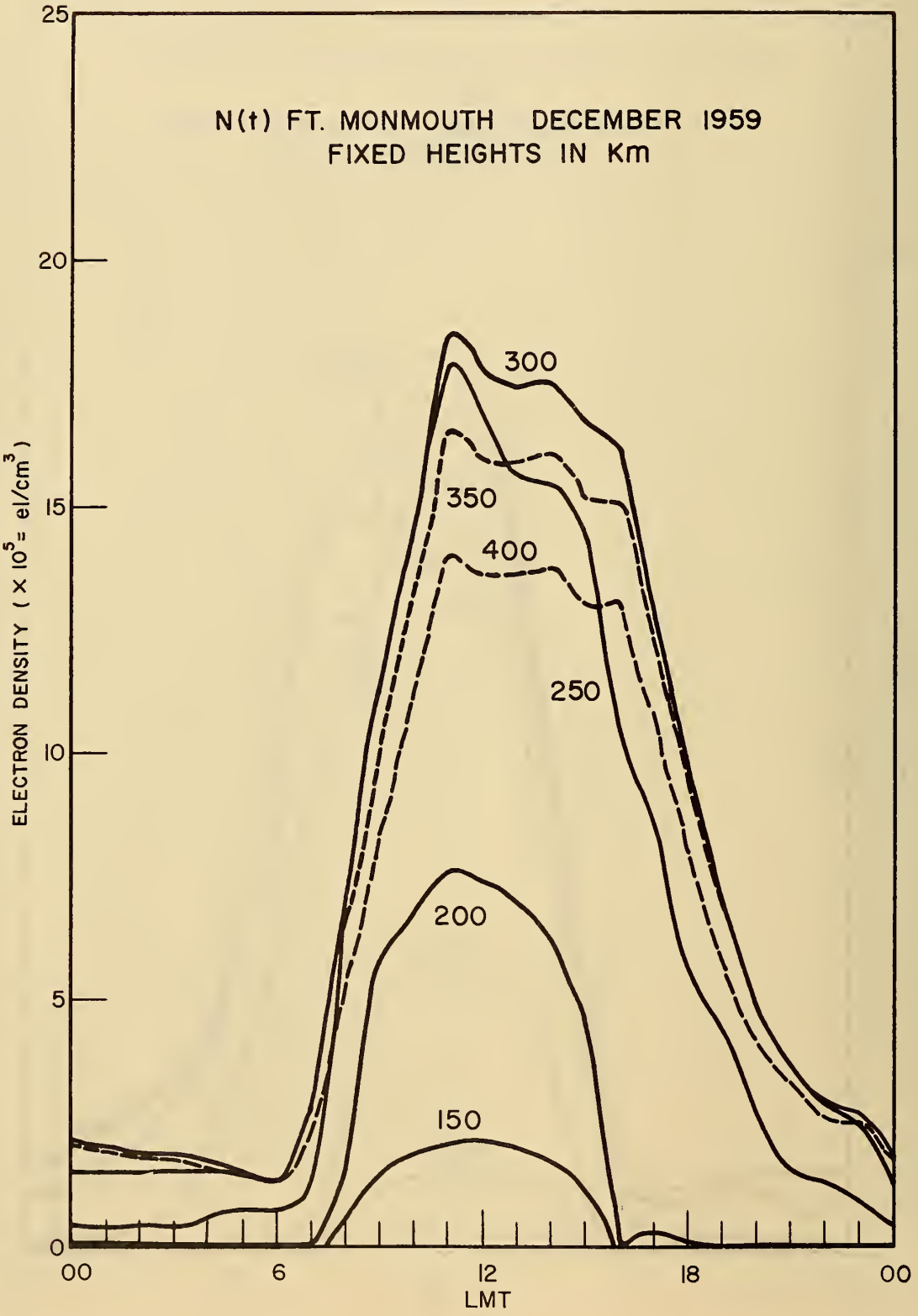
DEC. 1959

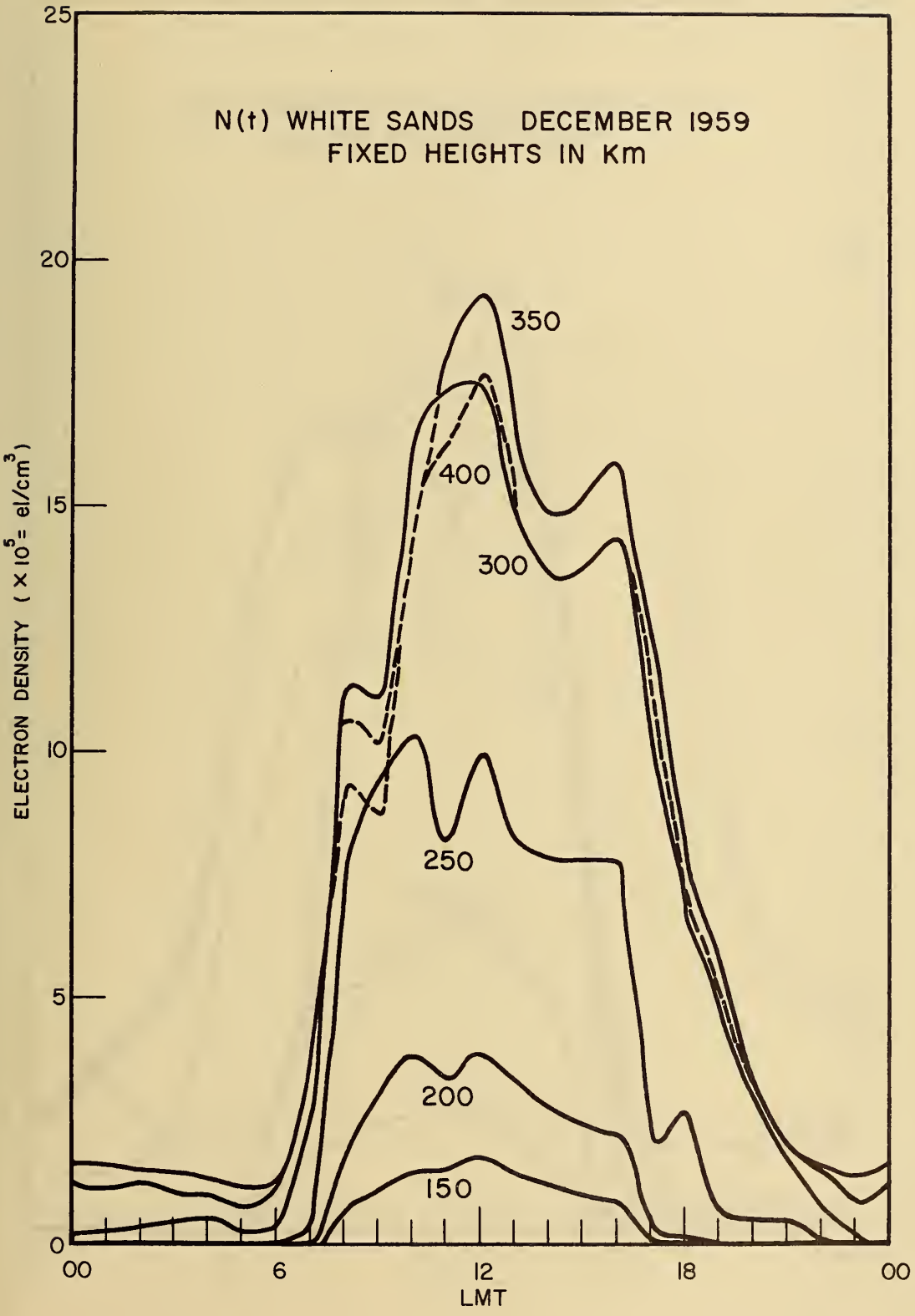


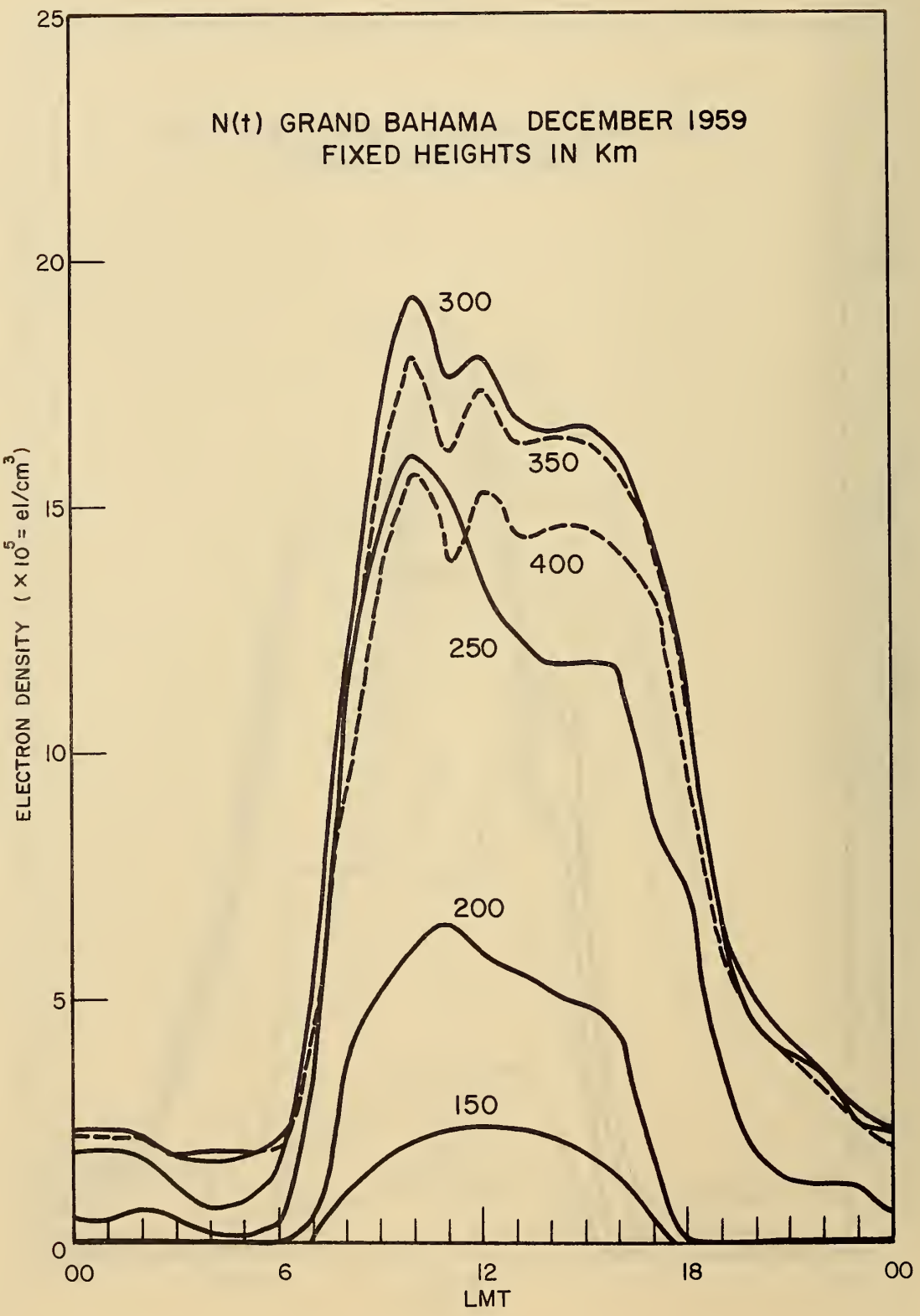
ELECTRON DENSITY INTEGRATED TO INFINITY
SHINF

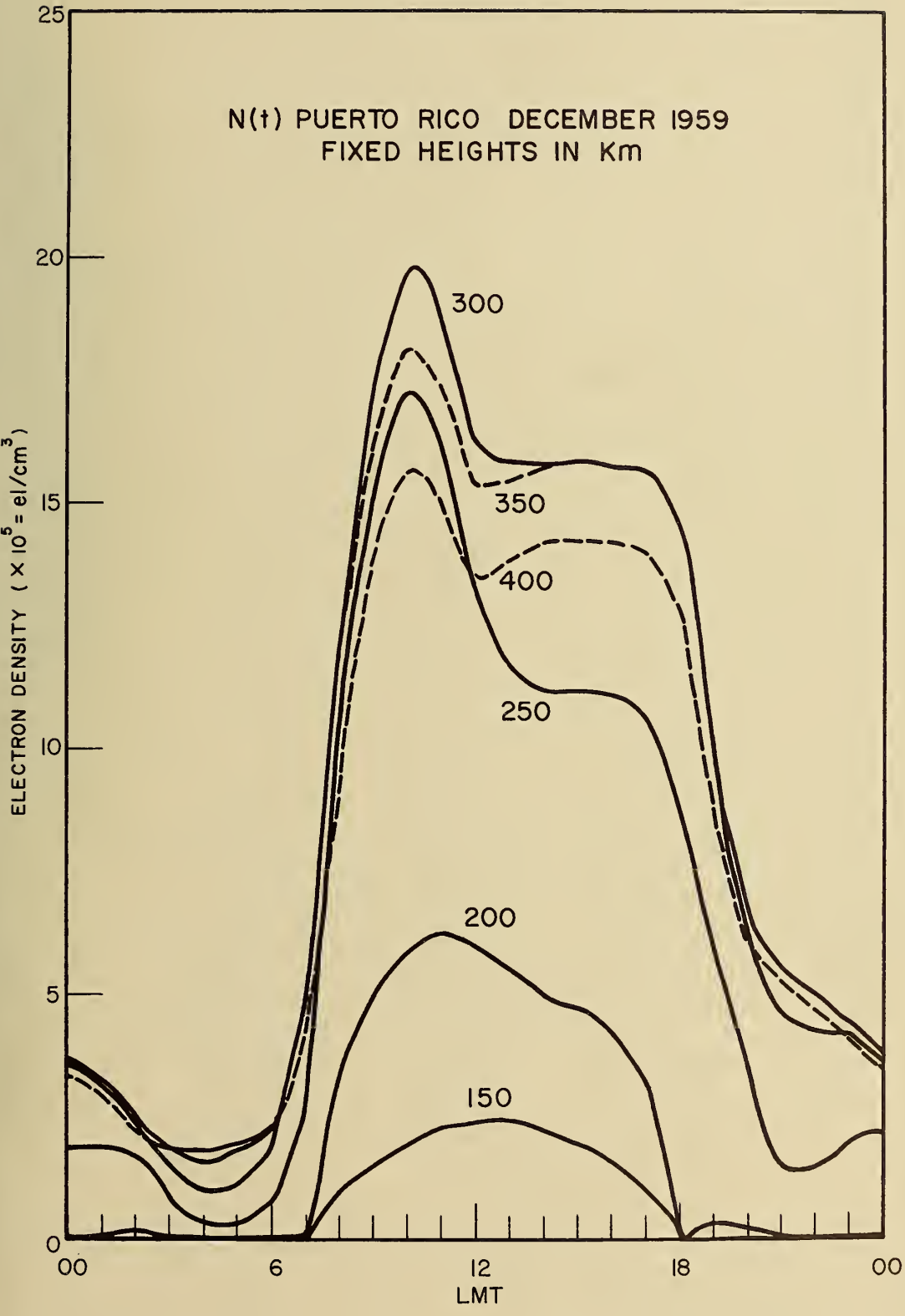



N(t) NEWFOUNDLAND DECEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (X10^5 = el/cm^3)
25
20
15
10
5
0
300
350
400
250
200
150
00
6
12
18
00
LMT


N(t) FT. MONMOUTH DECEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (X 10^5 = el/cm^3)
25
20
15
10
5
0
300
350
400
250
200
150
00
6
12
18
00
LMT


N(t) WHITE SANDS DECEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (X 10^5 = el/cm^3)
25
20
15
10
5
0
350
400
300
250
200
150
00
6
12
18
00
LMT


N(t) GRAND BAHAMA DECEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (× 10^5 = el/cm^3)
25
20
15
10
5
0
300
350
400
250
200
150
00
6
12
18
00
LMT



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U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

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Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

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Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

NBS